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The Society traces its origin to the *Philosophical Society of Australasia* founded in Sydney in 1821. The Society exists for "*the encouragement studies and investigations in Science Art Literature and Philosophy*": publishing results of scientific investigations in its *Journal and Proceeding* conducting monthly meetings; awarding prizes and medals; and by liaising with other learned societies within Australia an internationally. Membership is open to any person whose application is acceptable to the Society. Subscriptions for the Journal are als accepted. The Society welcomes, from members and non-members, manuscripts of research and review articles in all branches c science, art, literature and philosophy for publication in the *Journal and Proceedings.*

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Editorial

Robert E. Marks

A recent op-ed piece by a retired Australian politician argued that voters in Western democracies are exhibiting a distrust of elites and experts. This is seen in such recent results as the election in Australia of politicians from fringe parties (such as One Nation) and the election of Donald Trump in the U.S., people who explicitly deny recent scientific finds such as the evidence of global temperature rises partly as a result of human activity in the past two hundred years, and the absence of any evidence that vaccination can result in neurological damage to young people. The Brexit referendum in the U.K. is another manifestation of this phenomenon, as large numbers of voters ignored warnings by economists and others of the eventual adverse consequences of exiting from the European Union and the strong ties — social, familial, financial, legal, and economic — built up over the past forty years.[1] In his address printed below, Peter Baume cautions us against blaming many of these voters: they are, he argues, doing what they think is best for them. But it is a challenge for us.

As an aside, I'm grateful for compulsory voting in Australia, introduced federally in 1924 (although not for Aboriginal Australians until 1984) as the result of a successful private member's bill, after a decline in voting turnout from 71% at the 1919 federal election to less than 60% at the 1922 election. At the 1925 election the turnout jumped to over 91% (Evans 2006). Compulsory voting must provide electoral inertia against a lurch to extremism.

It is not necessary, in the organ of the Royal Society of NSW, to spell out why such mistrust in scientific expertise is of concern, but in 1995 the late Carl Sagan said it better than I could:

> "We've arranged a global civilization in which most crucial elements profoundly depend on science and technology. We have also arranged things so that almost no one understands science and technology. This is a prescription for disaster. We might get away with it for a while, but sooner or later this combustible mixture of ignorance and power is going to blow up in our faces." (Sagan 1995).

And, as others have said, it's blowing up already. Which is why institutions such as the Royal Society are so important.

Author Arthur C. Clarke is remembered, *inter alia*, for remarking, "Any sufficiently advanced technology is indistinguishable from magic" (1973). The solid-state physics of our mobile phones, etc., let alone the use of relativity in GPS, must mean "magic" to most of us. So, we in the Western world are surrounded by magical devices. Is this involvement with magic a possible explanation for the recent flight from science and rationality evident in politics? If so, will better education overcome our descent?

One of the best recent initiatives of the Society's is the annual forum of the four learned academies — the Australian Academy of Science, the Australian Academy of Humanities, the Australian Academy of Technological Sciences and Engineering and the Academy of the Social Sciences in Aus-

[1] Not to mention the fraught frontier in Ireland.

tralia — the topic of which last November was Society as a Complex System: implications for science, practice and policy.

Complex systems, almost by definition, are not easily grasped and understood, even by disciplinary experts, especially when there is interaction among systems in distinct domains — for example, hydrological, climate-related, meteorological, and social. Such issues have been dubbed "wicked," a term first used in this context by C. West Churchman in 1967. Problems here are wicked not in the sense of being evil, but in the sense of being resistant to solution, because of complex interdependencies, or other stumbling blocks to resolution.

The 2016 Forum has resulted in nine papers in this issue, which Len Fisher summarises and considers: read his piece to see what I mean. Suffice it to say here that the complex issues covered include human population and the biosphere, climate change, health care, the Murray-Darling Basin, appropriate metaphors to describe the role of DNA in embryogenesis and the emergence of the individual, formalising and modelling complex systems, diaspora advantage, and communicating the science of complexity and the complexity of science. Several of these themes will be pursued at the 2017 Forum, to be held in November.

As well as Peter Baume's address at the Society Annual Dinner, 2017, mentioned above, there is a refereed paper by Salimi et al. on octopus hearing. The issue ends with four PhD abstracts from young researchers, chosen by their universities for the brilliance of their recent dissertations.

I thank Ed Hibbert, Rory McGuire, and Jason Antony for their assistance in the production of this issue, which marks a return to our publishing two issues of the *Journal* a year, in June and December. Remember, the Journal Archive can be found on-line, at https://royalsoc.org.au/links-to-papers-since-1856.

UNSW, Sydney,
31 May 2017

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Don't Blame the Unemployed

Peter Baume AC DistFRSN

Distinguished Fellow's Lecture
Annual Dinner of the Royal Society of New South Wales,
The Union, University and Schools Club
25 Bent St, Sydney, 3 May, 2017

Professor Baume studied medicine at the University of Sydney, General Hospital, Birmingham, and as a U.S. Public Health Service Fellow in Nashville, Tennessee. He practiced as a gastroenterologist and physician in Australia from 1967 to 1974 and received his M.D. from the University of Sydney during that time. From 1974 to 1991 he served as a Senator for New South Wales. He held a number of portfolios, including Aboriginal Affairs, Health, and Education, and was a member of Cabinet. From 1991 to 2000, Professor Baume was Professor of Community Medicine at the University of N.S.W. He was on the Council of the Australian National University from 1986 to 2006 and was Chancellor of A.N.U. from 1994 to 2006. He has also been Commissioner of the Australian Law Reform Commission, Deputy Chair of the Australian National Council on AIDS, and Foundation Chair of the Australian Sports Anti-Doping Authority.

Did you know that the good food you have just eaten demands a quarter of all your blood for digestion and absorption, and this can lead to anyone becoming somnolent—in spite of anything that is done? That is why the post-prandial speaking slot and after-dinner addresses are so dangerous.

But what a distinguished audience this is. If one added all the higher degrees, all the titles, all the honorifics, in this room together with the many accomplishments of all the partners who mean so much, one is able to count so much talent and so much achievement—it is most impressive.

You, as members of the Royal Society of New South Wales, are enriching the communal debate and communal understanding. Your regular lectures raise topics that would not otherwise be raised and they provide platforms for worthwhile arguments that would not otherwise be heard. Your monthly meetings are valuable and worth attending. Where else would a mere doctor learn about beer, and botanic gardens, and Antarctic photography? You are thoughtful and distinguished and contributing to society.

Let me put one—just one—serious proposition to you to start.

Let me first tell you a story. An Australian recently visited Detroit and called a taxi. When it came it was filthy. So he called another taxi. It too was filthy. Later he was told by American friends that people who drove taxis in Detroit generally lived in those taxis because they were too poor to live anywhere else.

Against the background of that story, will you now consider the unexpected Brexit result in Britain, the election of Donald Trump as President of the United States of America, the election of Pauline Hanson to the Australian Senate, the rise of Marine Le Pen in France, the movement away from established political groupings here, and more?

Why has it all happened? Where is it leading? Why were they elected? And by whom? Well, let me try to guess.

They were elected properly under systems that we have designed. But so was Hitler elected. They were elected by people who were angry, people who had lost faith with established political parties, people who were under threat — as they saw things — people who were nostalgic for some mythical bygone era, people who were alienated, people who had nothing to lose and people who think that politicians do not care and do not understand. People who wanted to hear simple answers to complex and difficult questions.

They wanted to change the system and they had votes. They were not happy with the arrangements that exist. They did not like our values, or our society. They saw in those people they voted for some prospect for real change. And the movement they have started is not over.

More protest votes. More racist and anti-immigration votes. More votes for Pauline Hanson and her detestable views. Did you know that David Marr wrote an essay about her recently called "The White Queen"? It was a good title. But returning to my predictions: more votes for populists. More votes for one issue people. It will all continue.

Given all these things, and, in addition, given inequality, given lack of opportunity, and given political failure, why should the young — our young (our grandchildren and grand nephews and nieces) — comply? Why should they adopt the form of society we have and we have shaped and we have asked them to adopt? Why should they go to school? Why should they stay out of the workforce until they are fifteen? Why should they not die in despair from suicide? Why should they not try to change the society which cannot deliver to them what are not unreasonable demands for their lives? Why should they not be revolutionaries?

And we are creating or allowing to be created an ever more unequal society that the young might want to change. There is no justification for CEO salaries that are 300 times what someone on the factory floor earns, or what someone who delivers the mail is paid.

If there is no place for the young in this society, if there is great inequality, no hope, if there is systemic and systematic disadvantage, then they might try something different. It might be a fundamentalist society. It might be a totalitarian society.

Added to that: if automation proceeds — as it will — we are going to have driverless cars to go with the driverless trains we already have.

There go professional drivers. If clever robots can work 24 hours, then we do not need people in factories. There go manufacturing jobs. We all go to the ATM for money. There go bank jobs. You know about climate change. There go coal mining jobs. We do not need secretaries, or telephonists, or as many shop assistants as we did. There they go. Did you see the segment with Stan Grant last Friday? There went ward clerk jobs. There went many cleaning jobs. And so on.

Yes, there are going to be new jobs. Lots of new jobs. Lots of sunrise industries. But there are probably going to be fewer paid jobs overall, not compensated by new industries and the increased need for personal care workers. There are not going to be enough paid jobs to go around: let us accept that this is so.

Then the questions change.

Let us not blame people if they get no paid work. It is not silly for the union movement to propose a four-day working week. It makes the available paid work go around. How much they are paid for those four days

is another question. Let us teach people to use leisure productively, because they are going to have increased time and increased leisure. Let us encourage people to learn more. Let us encourage people to be carers: we are going to need so many more of these as the grey tsunami bears down.

But let us do something to welcome and encourage people instead of blaming them and stereotyping them. Trying to maintain the status quo without serious talk is not enough.

Now that is the end of serious talk. Let us be a little lighter and tell you what Parliament was like. Mind you, it is one thing to talk about how it was then: it is certainly different today.

You might care to know that in pre-revolutionary France some people referred to Versailles as *"ce pays ci"* — this special land — and politicians and their staff regard Canberra as much the same. They talk about minutiae, about what goes on in Canberra, about the relationships between certain people, and they think that those things matter and they think we are interested in those minutiae. Of course, they are wrong. We actually care about wider issues.

The first thing you might consider is that the Parliament represents the community that elected it. This is really frightening — or it should be: there are eggheads, like us, there are ignoramuses, there are racists, there are ideologues, there are conspiracy theorists, there are businessmen and women, there are slobs, there are average people, there are people of all sizes and shapes. There is Pauline Hanson and her horrible acolytes, there is Jacqui Lambie, there is Derryn Hinch, there is Cory Bernardi. They are all there. They were all elected properly. They each represent a constituency.

When I first went there I realised how little I knew about how politics worked. A word about political parties. A colleague once said that members of political parties were either: mad, lonely, or ambitious, or a combination of those things. That is a sad statement, and parties need to be different again: they used not to be like that. Actually, there were — and are — a few people genuinely interested in the country, But it was possible to meet all those types — the mad, the lonely, and the ambitious — through a couple of decades or so in Parliament and longer in one major political party.

I remember telling some parliamentary colleague on the phone that he was mad, and a few minutes later he put his head into my room and said, "I am not mad." He was the person who announced, when the issue of equal employment opportunity became important, that "a woman's place is in the kitchen and the other room." His wife, to her credit, left him because of that.

One time the then young Paul Keating made a strong speech against Sir Reginald Schwarz who was then the Post-Master General. It was a really strong speech — and Keating is good at vilification. Tom Uren (who had been a boxer) told Keating that in Changi prisoner of war camp Reg Schwarz had been beaten daily for his underlings, of whom Uren was one. Uren then told Keating that if Keating attacked Schwarz again, Uren would hit him. The old Changi ethos was strong. It went across the chamber. Political foes had this tie from when they were all prisoners of war together and they looked after each other in Parliament.

One of my seniors had been on the awful Burma railway and he was treated always with great respect by the other side of politics — and he treated those on the other side

with great respect too. That same senior person called me into his Sydney office soon after I had been pre-selected. He said: "Your job is to introduce people if asked to and give votes of thanks. Otherwise you are to be silent. Now, how do you take your tea?"

Which reminds me. My political patron John Carrick, now Sir John, had been in Changi as a prisoner of war. As a Minister he addressed a visiting Japanese delegation in Japanese. Apparently, the delegation knew his story and recognised prison-camp Japanese — and bowed very low.

The best remembered day in Australian politics was November 11th, 1975. It is told that Whitlam strode back into Parliament, saw the young Keating, a Minister for three weeks, pointed at him, and shouted: "Keating, you're sacked!"

On that fateful day, a message was passed down our ranks in the Senate at about 2.20 P.M.: "Don't let your expression change. Whitlam has been sacked. Malcolm is the Prime Minister. We are getting the Budget as quickly as possible. Pass it on." That is history as it is not known to most people. Had the Labor leaders in the Senate had prior knowledge of the events that day, the procedure they adopted would have been different and they might have won.

It is also recounted that just before a swearing-in, Whitlam met parliamentarian Barry Cohen looking morose. It transpired that Cohen — a Jew — lacked a yarmulke for his swearing-in. It is told that Whitlam took Cohen to his desk, opened a drawer, and said: "What colour, comrade?"

My own election took 35 days to be final. The Hare-Clark system is very fair but very slow. Actually, when it was final, we heard about it on radio through my beloved mother-in-law. My party never told me.

Many strange things happen in the Parliament. Bill Wentworth was one of the most intelligent men I ever met. He was brilliant. He was also too conservative for me. He was the driving force behind a uniform rail gauge for Australia and advocated a harbour tunnel ten years before others. People said he was mad on both issues. But they came to pass. Before he died, he told me that there had to be a tunnel from the Spit to North Sydney. It will happen too. But apparently when he was speaking once, someone, probably Fred Daly, borrowed a waiter's white jacket and stood behind him solicitously while he spoke about "reds under the bed". That resulted in Daly being thrown out. It was Daly who said: "In the great horse race of life, always back self-interest. At least you know it is trying".

Which reminds me. Once, in my medical days, the Prime Minister was ill and I was involved peripherally in his care. So, when, subsequently, I was elected, the only person I knew well — from the other side of politics — was the Prime Minister, and his behaviour towards me was always as impeccable and friendly as the treatment I got from Fraser and Anthony.

Some very strange things happened in Parliament. When I first went there I was told that there were three things new people had to learn then. They were: more people have talked their way out of Parliament than have ever talked themselves in; when the person in the chair stands up, you sit down; and do not eat the fish. Today that is not so — the fish is quite safe to eat.

I was also told that the people opposite were the opposition. If it was enemies you wanted to find, you had to look around you at people on your own side. The Senate committee system meant that I got to know a lot

of political opponents. They wanted many of the same things I wanted for Australia — they just had different ways of getting there.

Fred Chaney once told me a story about getting angry. Apparently, Doug Anthony, then leader of the National Party, told Chaney to get angry only on purpose. Just then there was a visitor and Anthony become very angry — thumping the desk and shouting. He turned to Chaney and winked. It was all put on.

Once as a minister I attended a Commonwealth Heads of Government meeting in Melbourne. Someone had threatened to kill me and so my wife and I were transferred from our insecure motel to a secure suite in a hotel with an armed guard in the next room and our car was tracked by traffic and got all green lights. The strange thing was that our children were in Sydney and no one worried about *their* safety — except us.

There used to be bipartisanship on many issues. I recall that Neal Blewett wanted to bring in a beaut policy for the then fatal illness of HIV infection. It was possible for my side of politics to let it pass without comment — they "looked the other way" — and Australia led the world with that policy.

In the old Parliament House we had a bowling green and a bowling club. It was very democratic. At lunch-time we would play bowls with anyone who was there — often drivers and cooks and cleaners and attendants. We played bowls against many of the local clubs and had mixtures of people in our teams. The new Parliament House does not have a bowling green.

By the way, the theatre of Parliament is always in the House of Representatives, while politeness reigns in the Senate. After all, the votes in the House of Representatives are certain. Theatre is all that remains. That is not the case in the Senate, which brings governments down from time to time.

There was another occasion — when I was a front bencher — that a health matter came up. My party wanted a certain amendment. Janine Haines from the Democrats listened to the argument and said "You've got me." I reported to my party that we had the Democrats. Not so. The Democrats were not bound by a party whip. We had Janine Haines but no other Democrat.

One never ceased being a doctor in Parliament. Labor people came to me. Our people went to Labor doctors: they were making sure that confidentiality was observed. Of course, many others came — attendants and staff, for example. It was mostly for repeat prescriptions (which they often did not want their colleagues to know about), ladies wanted the pill, and so on. Occasionally we had real medical emergencies, one person had a nasty corneal ulcer, one person had a stroke, there were heart attacks, and so on.

Naturally, we charged nothing — not least because we would have been in breach of the Constitution if we had accepted Medicare rebates. It has to do with holding an office of profit under the Crown. In any event, we were drawing salaries because of our main job.

In the same vein, long after I had entered Parliament, the Department of Veterans' Affairs wanted a report about a person who had seen me years previously, and the Department was willing to pay some money for that report. I provided the report but insisted that I was not paid, so the constitution was not breached.

The mail was delivered hourly, and hour after hour I watched a man who was obviously hypothyroid (a diagnosis that is missed easily, as Robert Clancy will attest) deliver

mail. Finally, it was too much for me and I intervened to get a blood test, which confirmed the diagnosis. Then I wrote to the local doctor and the man was treated. But the local doctor never acknowledged my letter.

Once, the President of the Senate became ill. He was Tasmanian and Labor, and one of the Labor doctors, also a Tasmanian — but from a different faction of the Labor party — insisted that I saw him so that no silly preselection questions would ever be asked. The Senate was then in a furious act of passing legislation at the end of session so the President was in and out of the chair minute by minute. It took about two hours to assess him. He had to go to hospital.

When I was first involved, community leaders — people like you —stood for Parliament, people who had good and worthwhile careers in the community in the years before they entered Parliament. They often used what they had achieved professionally as preselection talking points. If people tried to bully professional people, those professionals could tell them to jump in the lake.

Today, alas, we have too many professional party apparatchiks who have done no trade or profession apart from practical politics. They understand the pre-selection process and how parties work. They "game" the system and get pre-selected. Parliament is the poorer with this change.

We want people who have had a successful career. Parliament was serious but it was fun, too. It is poorer, and many of our young think it is irrelevant, if people like you are not part of it — if you are not in there yourselves or vetting those who wish to enter Parliament.

So please enjoy your evening. And help run a better Australia.

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A computational model of the responses of octopus neurons in the PVCN

Nima Salimi [1]*, Muhammad S. A. Zilany [1]

[1] Department of Biomedical Engineering, University of Malaya, Kuala Lumpur, Malaysia

* Corresponding author.
Email: nimasalimi64@gmail.com

Abstract

Acoustic information can be detected and processed through the auditory pathway in a very fast and complicated way. A large number of studies have investigated sound encoding at different levels of the auditory system by recording direct neural responses to different types of stimuli. However, processing of more complex stimuli at higher auditory centres is not well understood yet. Computational modeling has emerged as a new approach in order to obtain at least some insight into mechanisms underlying processing of complex sounds such as speech, animal vocalization, and music. In this study, the main goal is to develop a phenomenological and computer-based model of octopus neurons in the posterior ventral cochlear nucleus to simulate the physiological responses to simple and complex stimuli. Octopus cells receive synaptic inputs from a number of auditory nerve (AN) fibers; as a result, an AN model developed by Zilany and colleagues has been used to provide input to the proposed model. The summation of weighted outputs from the AN model has been subjected to a power-law adaptation function to simulate octopus cell responses. Model responses are compared to the actual physiological data recorded from octopus neurons. Output of the proposed model can be applied as an excitatory input to model responses of superior paraolivary nucleus neurons located in the superior olivary complex and also in the model of sound localization.

Key Words—Octopus cells, acoustic information encoding, neural response simulation, brain modeling

Introduction

Sound is an acoustical pressure which contains two important features, namely, frequency and intensity (Pickles, 2012). In the auditory system of the brain, sound attributes are represented by action potentials (characteristic electrical pulses) of neurons (Dayan and Abbott, 2001). Each cell (neuron) type of the auditory pathway plays a specific role in encoding important features of the sound. The pure tone, the simplest form of sound, has been used in many electrophysiological experiments to investigate how the auditory system of mammals, including human, encodes related information (Carney, 2002). However, since the auditory system is not linear, responses to the pure tone cannot be simply applied to explain processing of complex sounds (such as speech). Developing a computational model based on existing physiological data could be a helpful approach to test our understandings regarding the ways in which complex sounds are processed through the auditory system. The main aim of this study is to develop a computational model of the responses of the octopus cells in the cochlear nucleus. Octopus cells are very helpful in terms of encoding the precise temporal features of the natural sounds. These neurons occupy a separate region within the posteroventral cochlear nucleus (PVCN) of all mammals (Golding

et al., 1995) and receive inputs from a great number of auditory nerve (AN) fibres. Low input resistance as well as short time constant are the most significant properties of octopus cells (Bal and Oertel, 2007). Moreover, these neurons make one of the major pathways in which acoustic information can be conveyed from the auditory-nerve fibers into the upper levels of the auditory system (Bal and Oertel, 2001 ; Salimi et al., 2017). Two types of physiological responses to pure tones at the characteristic frequency (CF) have been shown for octopus cells based on their post-stimulus time histogram (PSTH) responses. These two types of responses are onset-locker (OL) and onset-ideal (OI) (Godfrey et al., 1975). The OL type has a very precise response at the onset of the stimulus which is followed by a very small sustained activity, while the OI type shows only an onset component. It is important to note that this onset pattern can be observed in response to stimuli with frequencies more than about 2 kHz. In addition to pure tone, responses of octopus neurons to more complex sounds such as sinusoidally amplitude-modulated (SAM) stimuli have also been recorded in the physiological experiments.

Different mechanisms have been suggested to model the response properties of octopus cells in the PVCN. In the study by Cai et al. (2000), the octopus cell was assumed to be sensitive to the rate of change of its membrane potential. The onset response to the pure tone was simulated by activating a low-threshold potassium channel during ramp-up stage of the input current. In another study by Sumner et al. (2009), the onset response of the octopus cells was simulated by auditory-nerve innervations and the dendritic filtering. Although the above-mentioned models successfully simulated the responses of octopus neurons to the pure tone, the model responses to the SAM stimulus were not evaluated.

A new mechanism, power-law adaptation, has been suggested in this study to simulate the physiological responses of octopus cells to both the pure tone and SAM stimuli. Next section describes the details of the approach used to develop the model of octopus cells in the PVCN. A comparison between the responses of the model and actual physiological data is provided in the Result section, and the final section provides the conclusion of this study.

Method

The approach applied to develop a model of the physiological responses of octopus cells is discussed in this section. Figure 1 shows the schematic diagram of the proposed model. As discussed earlier, octopus neurons receive their inputs from the auditory-nerve (AN) fibres, and thus the responses of the AN model (Zilany et al., 2009) have been used as an input to the model of the octopus cell. Most of the nonlinearities observed in the recordings of the auditory-nerve fibre such as nonlinear tuning, compression, two-tone suppression, level-dependent phase, and adaptation, were successfully captured by the AN model used in this study (Zilany et al., 2009). The AN model responses were validated against a wide range of actual physiological responses from the experiments, including PSTHs to simple and complex stimuli. The ability of the AN model to replicate the phase-locking property to the envelope of the SAM stimulus is another important aspect of the model used in this study.

Figure 1: A schematic diagram of the model of the octopus neuron in the PVCN. The input to the model is an acoustic stimulus which is passed through the model of the AN fibre. The model AN responses for a range of CFs are weighted and added together before a power-law adaptation function is applied. The final output of the model is the simulated responses of the octopus neuron.

In order to predict the responses of octopus cells, the simulated responses from five auditory-nerve fibres were weighted and added together. The range of CFs for which AN outputs were simulated was set to 2 octaves higher and lower than the CF of the corresponding octopus neuron. Then, the output of this stage [$r_{AN}(t)$] was subjected to a power-law adaptation (PLA) function (Eq. 1). Power-law adaptation is increasingly common in describing the dynamics of biological systems including sensory adaptation. Power-law dynamics can be approximated by a combination of exponential processes with a range of time constants and thus can model the coexistence of multiple time scales in a single adaptive process (Brown and Stein, 1966; Thorson and Biederman-Thorson, 1974; Drew and Abbott, 2006; La Camera et al., 2006). Note that octopus cells in the PVCN are at least a synapse away from the AN fibres, and thus multiple processes (e.g., depletion of "readily releasable" pool, endocytosis, exocytosis, and postsynaptic receptor desensitization) with a range of time constants could contribute to the neural adaptation (Raman et al., 1994; Moser and Beutner, 2000; Spassova et al., 2004). The PLA function was employed in this study to simulate the adaptation process between the AN fibres and the octopus cells. It is worth noting that the power-law dynamics have also been employed to explain complex and diverse adaptation in the synapse between the inner-hair cell and the auditory nerve (Zilany et al., 2009; Zilany and Carney, 2010). Since the rate cannot be negative, the output of the octopus cell, $r_{oct}(t)$, was derived as follows:

$$r_{oct}(t) = \max[0, r_{AN}(t) - I(t)],$$

$$I(t) = \alpha \int_0^t \frac{r(t')}{t-t'+\beta} dt' \qquad (1)$$

Applying appropriate weights for the AN model responses and setting both the values of a and β to 9×10^{-6} (or 12×10^{-6}) could lead to simulating the OL (or OI) type responses of octopus cells. Responses of the proposed model to the pure tone and sinusoidally amplitude-modulated stimuli were compared to the corresponding physiological responses reported in the literature.

Results and Discussion

In this section, the responses of the proposed model are compared to the actual data recorded in the relevant physiological experiments. Two types of responses to pure tones as well as responses to the SAM stimulus are considered.

Octopus cell responses to the pure tone

The model and actual octopus cell responses are illustrated in Figs. 2 and 3. In order to have a reliable comparison, stimulus conditions were matched to those of the respective physiological study. By setting the values of

a (dimensionless) and β (s) of the power-law adaptation function to 9×10^{-6}, the proposed model was able to replicate the OL-type responses to the pure tone (Fig. 2). Both the physiological (A) and model (B) responses showed an onset component which was significantly higher than the sustained part. In addition, a very short duration of suppression was observed immediately after the onset component in both the model and physiological responses. Moreover, the sustained component gradually declined as a function of time.

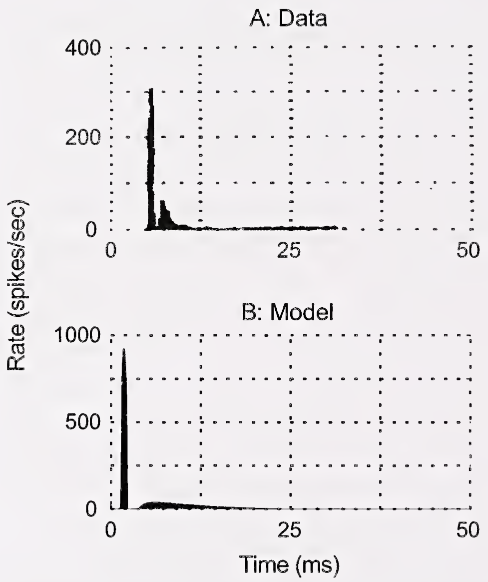

Figure 2: Actual physiological (A) and model (B) responses of an octopus neuron. The input stimulus was a pure tone at CF. The model responses (B) resembled the onset-locker (OL) type of responses recorded in the electrophysiological experiment (A). Stimulus parameters: CF = 9.5 kHz, sound level = 55 dB, duration = 25 ms. Actual data are reproduced from Godfrey et al. (1975).

In order to model the OI type of responses, the values of a and β had to be increased to 12×10^{-6}. Figure 3 shows the actual (A) as well as model (B) responses of an octopus cell to the pure tone at CF (7.8 kHz), and the duration and level of the stimulus were 25 ms and 55 dB SPL, respectively. It is obvious that both the model and physiological responses showed a remarkable onset component with a zero sustained activity.

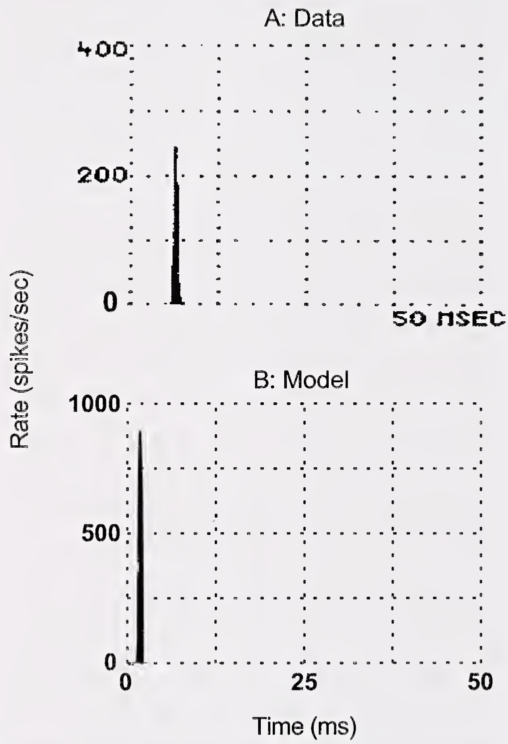

Figure 3: Actual physiological (A) and model (B) responses of an octopus cell to a pure tone. The proposed model was able to simulate the onset-ideal (OI) type of responses, which is consistent with the physiological responses using the same stimulus conditions. Stimulus parameters: CF = 7.8 kHz, sound level = 55 dB SPL, and stimulus duration = 25 ms. Actual data are reproduced from Godfrey et al. (1975).

Octopus Cell Response to the SAM Stimulus

SAM stimulus can be defined as

$$S(t) = \left(1 + m\,sin(2\pi f_m t)\right) \times \sin(2\pi f_c t), \qquad (2)$$

where f_m is the modulation frequency, f_c represents the carrier frequency, and m determines the modulation depth of the signal.

In order to show the modulation transfer function (MTF) of the octopus neuron, responses to the SAM stimulus were simulated for modulation frequencies ranging from 50 to 2550 Hz. The carrier frequency of the signal was matched to the CF of the unit in the relevant experiment (indicated in Fig. 4). Then, from the model responses, sync-MTFs (synchrony coefficients versus modulation frequencies) and rate-MTFs (rate versus modulation frequencies) were constructed at different sound levels to compare with the corresponding physiological responses from the experiments (Rhode and Greenberg, 1994). The stimulus duration was set to 1 s for simulating model responses which was different from the stimulus duration of the respective physiological study (T = 100 ms). However, this difference did not affect the trend observed in the obtained results. Figure 4 represents the actual and model rate-MTFs in panels A and C, respectively. The sync-MTFs from the actual physiological experiments and model responses are shown in panels B and D, respectively. Note that the MTFs were obtained for the OL unit only.

The rate-MTF of the model responses was typically low-pass or flat in nature, which is consistent with the physiological responses. However, the cut-off frequency of the model rate-MTF was much lower than the cut-off frequency of the actual responses (~300 Hz versus 1000 Hz). In addition, changes in the rate as a function of the sound intensity showed a different trend between the model and actual responses, which could be attributed to the power-law adaptation function (i.e., parameters) employed in the proposed model. In terms of the sync-MTF, model responses were low-pass in shape for all stimulus levels studied. However, shape of the sync-MTF related to the physiological data was low-pass at lower sound intensities and became band-pass at higher sound levels (around 70 dB SPL).

It is worth-noting that the minority of the octopus cells had a low-pass sync-MTF for all intensities tested (Rhode and Greenberg, 1994). Again, the cut-off frequency of the model sync-MTF was much lower than the cut-off frequency of the physiological sync-MTF. In addition, the cut-off frequency of the model sync-MTF increased with increasing the sound level, whereas in the physiological responses, the cut-off frequency remained relatively constant with the sound level.

Conclusion

A computational model to simulate the responses of octopus cells is proposed in this study. Responses of the model auditory-nerve fibres were simulated at the first stage of the proposed model. These responses were weighted and summed and then applied as an input to the power-law adaptation function. Setting appropriate parameters for the power-law adaptation function led to simulating the octopus cell responses for a reasonable range of sound intensities and frequencies. The proposed model was able to simulate physiological responses of octopus neurons to both the simple and complex

stimuli. The output of the proposed model can be applied as an input to the model of neurons located at higher levels of the auditory pathway.

Acknowledgements

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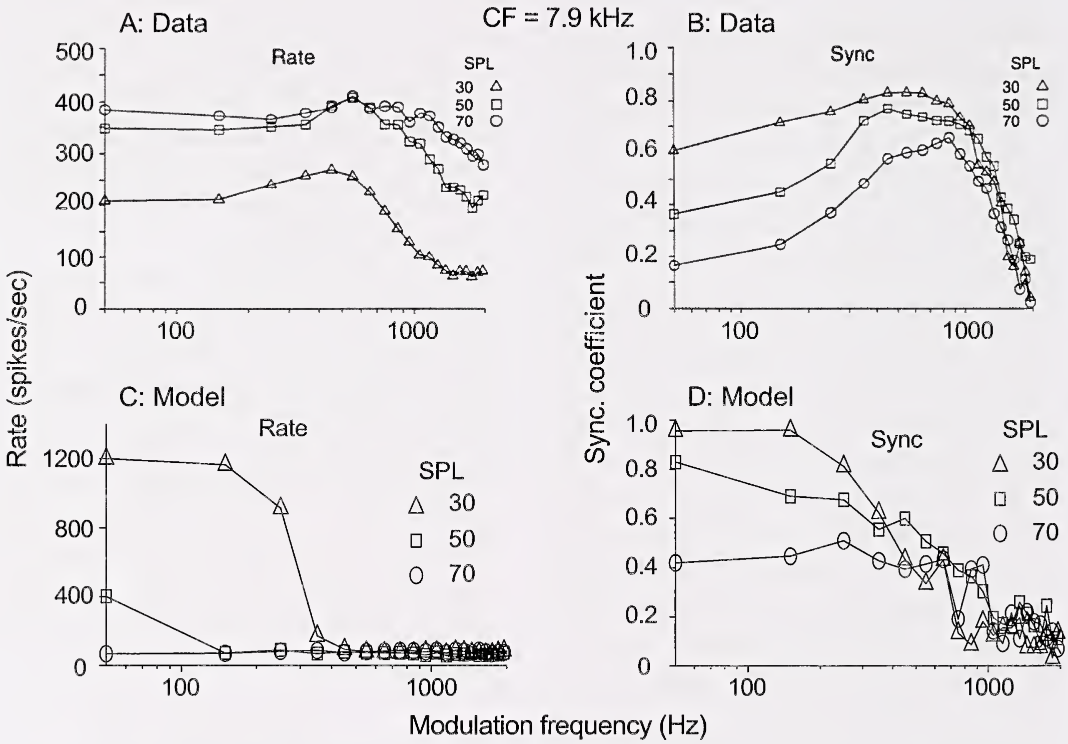

Figure 4: Actual physiological (A and B) and model (C and D) responses to the sinusoidally amplitude-modulated stimuli for three different sound pressure levels (SPLs). The stimulus intensities (SPLs) are indicated in each panel. Panels A and C show discharge rate as a function of modulation frequency, while panels B and D illustrate synchrony coefficient as a function of modulation rate. Generally, the model responses followed the trends observed in the physiological responses. However, model responses were suppressed at the lower modulation frequencies compared to the responses from the physiological data. Actual data are reproduced from Rhode and Greenberg (1994).

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Forum: Society as a complex system: implications for science, practice and policy

His Excellency, David Hurley

Governor of New South Wales

Abstract

This is opening address given by Governor David Hurley to the *Royal Society of New South Wales and Four Academies Forum on Society as a Complex System: implications for science, practice and policy.* This was held at Government House, Sydney, on Tuesday, 29th November, 2016.

I would like to pay my respects to the traditional owners of the land on which we gather, the Gadigal people of the Eora Nation. I affirm my respect for their elders, ancestors and descendants—and all Aboriginal people. I recognise their living culture and their knowledge, as the world's oldest continuing culture, which has sustained this land for tens of thousands of years.

As Patron of The Royal Society of New South Wales, I am delighted to welcome all delegates and attendees to this *Royal Society and Four Academies Forum: Society as a Complex System.*

I thank you for your eminent contributions to this Forum, being jointly held by The Royal Society and the New South Wales Chapters of Australia's four learned Academies—the Australian Academy of Science, the Australian Academy of Humanities, the Australian Academy of Technological Sciences and Engineering and the Academy of the Social Sciences in Australia.

I was taught very early in my military career never start a speech with an apology. I will this morning, though, because since we had our power cut off last week—not because we don't pay our bills here, but some workers down the road decided to sever our cable—we've had lots of problems getting things started up again and I'm afraid the air conditioning's not playing the game today. So, if you need to be in a shirt and tie, please do take your jackets off until we sort something out.

I'm used to "wicked" problems, having worked in the Defence force and looked at trying to determine 20, 30, 40 years down the track what the world will be like. What will conflicts look like, what will the national security condition be, what capabilities will the Defence force in 2010, for example, need in 2050? How do you answer those problems? Today, we, I think, dive further into looking at wicked problems in the sense we're going to look at society as a complex system. I think families are a bit like that, a bit of a microcosm of the problem, because if you look at the definition of a wicked problem or a super wicked problem, there are a number of elements or a number of characteristics: time is running out; there's no central authority—sounds like my household; those seeking to solve the problem are also causing it; and policies discount future rationalities. This is the nature of the problems we'll be looking at today.

If you look at Sydney at the present time, you've no doubt seen the debate that's going on, the discussion between ministers, plan-

ning, industry, the business community and the population and the media about what Sydney will look like in 2026, only 10 years away from now. Our economy is moving from a traditional manufacturing-based economy to a digital- and technology-driven economy. Indeed, IBM says that the amount of data that was produced in 2002 is now produced every two days, under current technology, with all the different systems we have. We've become heavily reliant on a knowledge-based economy. Indeed, in 2026 it is predicted that the three dynamic service industries in New South Wales will be finance, professional services, and information and telecommunications. A drastic change in the economic base of our country. And, of course, this will affect employment, education, housing and health — some of the areas we'll touch on today. So, what our plan is in the State, how our leaders, how those who input into those discussions, will help solve these problems are critical.

As I alluded to last night, the implications for what we'll look at today about how governments and how bureaucracies organise themselves and who the new stakeholders are in these decision-making processes will become important. Are you a good or a poor insurance risk for health? Big data is going to tell us this. Insurers are now searching big data. Your Fitbit, if you wear one, will tell your insurer whether you're a good or a bad risk. These links, which we would never have thought of before, are actually influencing the way business is being done, how people see the world. How to design a health system around the delivery of personal medicine when every bit of data about a person can be known? Where's the dividing line between privacy and public health requirements, national cost of servicing health? These are problems, I think, that will keep popping up until, somehow, we can provide a means for our decision-makers to address them. And if you think your premium for private health is too high now, watch it go up if you fall in the wrong category. And, indeed, who looks after the uninsurable? These are all problems, I think, that our discussions today can assist. I mentioned the Murray–Darling Basin system last night, I keep coming back to it. It intrigues me and I'm really looking forward to that discussion today about what we do with this major water system.

As you've seen from the agenda today, I think we're in for an extraordinarily absorbing period together. I look forward to the Q and A. I come from an Arts background so I'm pretty much in the wrong audience here but, as I mentioned last year, I did do my degree in pure mathematics, so, even though I didn't use it once I left Royal Military College, I could count the number of soldiers I had in my platoon. That was about the amount — and did I have the same amount in the morning as I had the night before? Yep, we're okay. So, I'm really looking forward to some stimulating presentations today, great discussion and questioning.

On that note, I won't say any more other than to say, again, happy 150th birthday to the Royal Society — 150 years since the Royal Assent — and to declare the 2016 *Royal Society of New South Wales and Four Academies Forum: Society as a Complex System* at Government House open.

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Society as a complex system: how can we make the best decisions for our future?

Len Fisher

School of Physics, University of Bristol, Bristol, UK

Email: lenfisherscience123@gmail.com

Abstract

The papers in this volume examine, through the lens of complexity science, some of the major problems that society now faces. Here I review the insights that have emerged, and ask how those insights might be used to help us make better decisions for our economic, social and environmental futures.

Introduction: What is a Complex System?

As spelled out by several authors (e.g. Finnigan, Prokopenko) in this volume, a complex system is an assemblage of components that interact with each other in a non-linear way, so that the *emergent* properties of the system as a whole are different from the summed properties of the individual components. Most ecosystems, economies and societies fit into this category. Those that are discussed in this volume are generally viewed as networks, consisting of *hubs* (biological organisms, people, groups of people, organizations, etc.) connected by *links* through which they interact. Most of the networks are *adaptive*, where hubs or links can change in response to their previous communication history. Links may get stronger or weaker; they may break, and new ones may form; new hubs may enter; interactions may reinforce or undermine.

Computer modelling has become the major tool for helping to understand these processes and their consequences. Economist and complexity thinker W. Brian Arthur, writing in *43 Visions for Complexity* (2017) points out that "in no small way [our understanding of] complexity has come out of the arrival of computers. Before computers, if we wanted to understand systems, we had to treat them as linear, in stasis or equilibrium, predictable, and expressible in equations. Now, with the help of computers, we can look at systems that are nonlinear, not in equilibrium, not predictable, and expressible in algorithms … We are thus finding new insights into real-world systems."

Henrik Jensen, (2017) in the same volume, says: "A saxophone and a tree don't have very much in common. But a jazz band and a forest might very well have … as soon as one realizes that the world is made of interconnected processes … one immediately realizes why complexity science is the most fundamental of the sciences … ".

Real World Complex Systems

An understanding of complexity is fundamental to our understanding of the world, and new insights are certainly needed if we are to make the best decisions in an environment of complexity and uncertainty. As the Hon. David Hurley, Governor of New South Wales, points out in his opening address to the forum, the problems involved are

"wicked problems"; that is, "social or cultural *problems* that are difficult or impossible to solve for as many as four reasons: incomplete or contradictory knowledge, the number of people and opinions involved, the large economic burden, and the interconnected nature of these *problems* with other *problems*" (Kolko 2012).

Hurley specifies some of the actual problems: "What will life and society look like in 30, 40 years? Who will be the stakeholders? Time is running out, we haven't got a central authority, this is a self-organizing system, and the people who are trying to solve the problems are often the ones who are creating them."

Wicked problems may not be able to be solved but, as John Camillus pointed out in an article in the *Harvard Business Review* (2008), at least some of them may be able to be tamed. To do so, however, requires a radical shift in the way that we understand and respond to such problems. The contributors to this volume discuss some important examples, with ramifications that extend well beyond the Australian context.

John Finnigan points out that complex systems have two important characteristics that distinguish them from systems that are merely very, very complicated. One is *emergence*. The second is *self-organization*, where the system will tend spontaneously towards some level of organization. Such systems have their own internal dynamics and attractors. So, for example, villages, towns and cities are "attractors in this space of people with a food surplus trying to organize themselves in an efficient way."

For most of the last 10,000 years, says Finnigan, a major attractor has been the "Malthusian trap", where population has stayed constant or changed relatively slowly. Following the Industrial Revolution, mankind has burst out of this trap into a state that Finnigan labels as "open access order," with faster population growth, "faster political and economic development … faster growing economies … more decentralised governments and more of the country's GDP going to support governments and impersonal relationships."

What are the safe boundaries in this era of rapid change? The biophysical boundaries in key areas such as biodiversity, climate change, and ocean acidification were analysed in a seminal paper from members and associates of the Stockholm Resilience Alliance (Rockström et al. 2009) entitled "A safe operating space for humanity". But these are not the only boundaries to be considered. As Raworth (2012) argued several years later, a safe *and just* [my italics] space for humanity requires the recognition of social boundaries as well.

Finnigan argues that these two sets of boundaries are, in some sense, incommensurate, and draws the stark conclusion that *a safe and just operating space for humanity is not an attractor for the human/earth system, at least with the settings that we have at the moment.*

What can we do about this situation? At the moment, not a lot. As Finnigan points out, "it's not easy to reach into a complex system and say that's the lever I need to pull. More often than not, it will have the wrong result. To take one example, sustainable development goals could be self-defeating if the underlying drivers are strongly coupled, so that the pursuit of these goals means that we are making something else much worse." Understanding such interactions must be a major goal of modelling, but there is a long way to go.

Unfortunately, as Brian Spies points out, there isn't much time, especially when it comes to the issue of climate change. Spies reviews the huge amount of evidence available, especially through the reports of the Intergovernmental Panel on Climate Change, and makes the point that the wording of the conclusion on anthropogenic contributions changed from "very likely" in 2007 to "extremely likely" in the 2014 report. The evidence, and the conclusions, can hardly be questioned at a scientific level. Its effect on policy, though, is a very different matter.

Policy, as Spies points out, is largely a matter of psychology, and people's choice of whether or not to "believe" in anthropogenically-driven climate change largely depends, not on the scientific evidence, but on their world view. As Garnaut (2008) pointed out, this makes climate change the hardest policy problem in living memory — one, moreover, where taking small actions to give the appearance of action is the most inappropriate, but most common, response.

Yet, with politicians unwilling or unable to grasp the nettle, that is precisely what is happening. Vested interests, from the oil and mining industries to the Heartland Institute, continue to promote the fallacy that the topic of climate change is controversial and uncertain. Policies for mitigation, such as the economist-supported emissions trading scheme, receive minimal or no support.

The alternative to mitigation is adaptation (Fisher 2015) — recognizing that change is inevitable, and preparing for it. Here it seems that, in the Australian context at least, things are happening, especially at local and State Government level. Local councils are cooperating to develop measures to cope with more frequent storm surges, and planning regulations are being put in place to allow for a possible 1m rise in sea levels.

One promising trend is that big financial institutions are beginning to sit up and take notice. Mark Carney, Governor of the Bank of England, has talked about climate change threatening financial reserves and long-term prosperity, while the Business Council of Australia has prepared a report on pathways to net zero emissions. The Australian financial systems regulator has also recently cautioned firms in the sector about ignoring the risks associated with climate change (ABC News 2017).

But, as Spies points out, there is still no roadmap (in Australia or in most other countries) to look for the longer-term.

Stephen Simpson, head of the Charles Perkins Centre at the University of Sydney, takes a different tack. A major programme at the Centre is the study of obesity. Simpson refers to a British-based foresight map demonstrating all of the factors that lead to an individual having a propensity to become obese (Foresight Obesity System Map 2007). The map has become known in the field as the spaghetti map, and it has in some senses paralysed the field because it is too complicated.

Simpson's answer is to "look for the really simple things... that can have the biggest impact." This seems to be in line with the concept of "influencers" of opinion in complex networks, although this concept has been challenged (Watts 2007). The topic is complex in itself, but certainly there is room to look for simple solutions before bringing the full panoply of methods to bear on the system as a whole. Hopefully, the obesity "epidemic" might prove to be such a case.

John Williams discusses the concrete case of the Murray–Darling basin, and whether it

is possible to bring the three big issues — the environment, productivity, and social well-being of its inhabitants — into some level of outcome inside a boundary of a safe operating space.

The problem seems simple — how much water can one take from the system for agricultural and other purposes? But one cannot take more out than is going in, and the rainfall that is the source varies enormously from year to year. Dams can help to even out the situation, but "Dams do not make more water. Rainfall does [this includes snow melt]." There is also the problem of groundwater, and the movement of salt, to factor in.

The river system itself is "a system of connected flood plains, billabongs and anabranches. … So the river system itself [fits the definition of] a complex system, but it's nested inside a complex, highly variable climate system." Furthermore, the climate system is so variable that the ongoing effects of climate change are going to be difficult to detect in the short term.

But the problem can be simplified. Measurements and calculations in the early 1990s showed that no more than 11,600 gigalitres per annum could sensibly be taken, whereas something like 14,000 gigalitres per annum was actually being taken. So in 1994 a cap of 11,600 gL/y was set. But how could this be made to happen in reality?

But "to bring about an environmental reform" Williams rightly points out "you need to find a way to manage the actual social and economic impacts." One way of doing this with the river system is to "buy back" water from willing sellers *via* a tender process, although the impact on towns in the Basin has led to a considerable push-back against this process. Another is to use infrastructure enhancement and subsidies through the private sector to help minimise water use. The details of how this is happening, and the ongoing political complications that it involves, are given in the paper. They provide an excellent example of the communication, persuasion, and tough decisions that are needed to turn scientific understanding into concrete action in our complex socio-economic-ecological world.

Paul Griffiths, a philosopher at the Charles Perkins Centre, expands on the issue of communication, and especially of communicating biological complexity. He makes the important, experimentally verified point that "If we are going to communicate biological complexity, then … audience effects, namely the filter that the audience imposes on the information [through preconceptions and limited knowledge/background] may completely drown out the scientific signal."

Mikhail Prokopenko, who leads the Centre for Complex Systems at the University of Sydney, addresses the practicalities of modelling complex systems. Prokopenko follows Finnigan in emphasising the distinction between complication and complexity, and further emphasised that a key idea in self-organized complex systems is that of conceptualising data into information.

Prokopenko's talk focuses on the modelling and dynamics of cascades and avalanches, with the initial example being that of the triggering of a snow avalanche, with which he drew the parallel of a technological avalanche in the failure of a power grid. A side comment here is that the technological avalanche could be controlled through a design that allowed parts to be isolated — a suggestion similar to that which has been made for the global banking system (Haldane & May 2011).

Social dynamics are factored in *via* the example of people using the infrastructure network — technology, cars, roads — for vacations, and the spreading of epidemics. "The problem," says Prokopenko "is that [when social dynamics enter the equation] there are more and more hidden variables [and] the nature of the interactions is less defined so that it is harder to influence ... There is also a self-referencing effect [where] the social behaviour that we are trying to engineer starts to feed back on to the rules of interaction."

Analysis of social dynamics is facilitated by the small-world model (Watts & Strogatz 1998) and the sorts of information transfer that occur within it. *Active information* "provides a clear distinction between the chaotic part of the network and the [predictable] ordered dynamics." *Transfer entropy* "is focused on changes in the system [and] the dynamics of that information as seen from its neighbours (see Prokopenko, this volume, for details). "To guide self-organisation," says Prokopenko "you have to look at [these] information dynamics [and] understand the cascades of information."

Fazal Rizvi focuses on the question of migration, and the fact that "people are dispersed but are remaining connected to a number of different places, often simultaneously and in an ongoing fashion [so that] networks are becoming really important."

Rizvi reports on a survey by ACOLA (The Australian Council of Learned Academies), which asked what contribution Asian Australians (some 16% of the population) were making to the Australian economy. The contribution of the diaspora was seen to be largely positive, but there is still some way to go before we understand "how the wealth of networks contributes to the wealth of nations."

Finally, Joan Leach, director of the Australian National Centre for the Public Awareness of Science, addresses the question of communicating the science of complexity to politicians and the public, beginning with Derek de Solla Price's notion that science itself is now a complex enterprise, and correspondingly more difficult to comprehend.

Another difficulty is that, with many segmented channels of information (and misinformation), audiences have also become segmented, and can choose the source or sources that reinforce their beliefs and prejudices. A third problem is that scientific literacy in the wider community is very low. This means (Fisher 1999) that scientific communication is often a two-step process, first, introducing the concepts, and then, showing how they apply to the problem. By the time that we have reached the second step, though, we have usually lost our audience.

Making the Best Decisions

What practical steps must we take to give ourselves the best chance of making the right decisions for our future in the face of the questions raised by the various contributors to this volume? The obvious recourse is to use computer modelling to help understand and predict the future behaviour of a system, and progress is being made in this direction (Prokopenko, this volume). It may also be possible to combine aspects of classical decision theory with agent-based modelling, and serious efforts are now being made in this direction (Elsawah 2015).

But we also need simpler, pragmatic approaches, and one of the roles of modelling must eventually be to check out the efficacy of these approaches. Three primary candidates are:

i) Simplifying the decision process.

ii) Using different criteria to allow for complexity in making the decision.

iii) Changing the system to improve control, resilience and predictability.

i) Cutting the Gordian Knot

"Make it simple. Make it quick."

Advice of title-winning English soccer coach Arthur Rowe.

One simple approach to solving complex problems was reputedly used by Alexander the Great when he visited the ancient city of Gordium, which stood on the site of the modern-day Turkish town of Yassihüyük, in 333 B.C.E. According to legend, the quasi-mythical King Midas had, some five centuries earlier, tied an ox-cart to a pole by means of an intricate knot that no one had been able to unravel in the intervening centuries. Alexander at first tried to untie the knot and then, when he could not even find an end, solved the problem in a rather more direct manner by slicing the knot in half with his sword.

Gerd Gigerenzer and his colleagues at the Center for Adaptive Behavior and Cognition in Berlin have shown that Alexander's direct, no-nonsense, simplifying approach can sometimes stand us in good stead when it comes to making decisions in complex situations. Rather than trying to allow for the complexities, they suggest, it can often be useful to adopt simple pragmatic rules that work in the majority of cases (Gigerenzer & Brighton 2009).

The beginning point is that our minds are simply unable to digest and process all of the information that might be necessary to reach a perfectly rational decision in the majority of circumstances. *Homo sapiens* ("thinking man") we may be, but Sherlock Holmes's we are not.

Gigerenzer and Gaissmaier (2011) argue that our normal brains have developed (presumably through a combination of emotional and rational experience) to use a range of simple practical heuristics as short-cuts to decision-making. Experiments by his group and others have shown that we can deliberately use such short-cuts ("fast and frugal heuristics") to make better decisions in complex situations. This approach seems to be especially applicable to making political decisions, where data are often inadequate and time can be short (hence the *dictum* "no more than can be written on one side of an A4 sheet").

Four of the major approaches suggested by Gigerenzer are:

Recognition: If faced with a pair of alternatives, choose the one that is most recognizable (this approach can easily be extended to a choice between multiple alternatives). In one study, for example (Ortmann et al. 2008), people with no prior knowledge of the stock market were able to construct portfolios that out-performed professionally managed funds, simply by investing in firms whose names they recognized.

Tallying: Look for cues that might help to make a choice between options, and go with the option that has the greatest number of cues (or the greatest excess of positive over negative cues if both sorts are available).

When hiking or skiing in avalanche areas, for example, there are seven major cues (including whether there has been an avalanche in the past 48 hours and whether there is surface water from sudden warming) that indicate potential for an avalanche. Studies have shown that, where more than three of these cues are present, the situation

should be considered dangerous. If this simple tallying strategy had always been used, 92% of historical accidents could have been avoided (McCammon & Hageli 2007).

An interesting exercise in tallying is a comparison between Magnetic Resonance Imaging (MRI) and simple bedside rules for the early detection of strokes (Kattah et al. 2007). The simple bedside eye examination consists of three tests, and raises an alarm if the patient fails any one of these tests. This simple tallying rule correctly detected 100% of patients who had had a stroke (with just one false positive out of 25 patients), and outperformed the complex MRI diffusion-weighted imaging, which detected only 88%.

Take the Best: When faced with a choice between two options, look for cues and work through them in the order of your expectation that they will lead to the best choice. Make the choice on the basis of the first cue that distinguishes between the alternatives.

Satisficing: Search through alternatives and choose the first one that exceeds the aspiration level. This technique has a rigorous mathematical basis (Todd & Miller 1999) that defines the odds of making the right choice — so long as the guesser can make a reasonable estimate of how many alternatives there might be without having to look at them all individually.

All of these simplifying approaches fit with the suggestion of Stephen Simpson (this volume) to "look for the simplest things that can have the biggest impact." But there is an important *caveat*. It is well-established (Scheffer 2009a; Fisher 2011) that *all complex systems carry within their very structure the seeds of sudden change*. Warning signs may be available (Scheffer 2009b), but the timescales for responsiveness of human political and administrative institutions are often slower than the timescale of the change itself (Biggs et al. 2009). This means that simple heuristic responses are not sufficient of themselves; *what is needed is a drastic improvement in the level of flexibility of human institutions so that decisions can not only be made quickly, but also changed quickly in response to circumstances.*

ii) Using Different Criteria to Allow for Complexity in Making the Decision

> "Everything should be made as simple as possible, but no simpler"
>
> *Albert Einstein* (attrib.)

The simple heuristic criteria listed above (and many others that are described in the references quoted) can often be useful in making personal decisions. For the reasons outlined above, they are not quite so satisfying when it comes to making important decisions about big social, economic and environmental questions. Is there some other approach that we could use; one that avoids the Procrustean nature of heuristic decision-making, but which also overcomes the difficulty of assessing "utility," as required by classic decision theory?

Steering a course between such a Scylla and Charybdis of decision-making in complex situations is by no means easy. Three major possibilities for alternative criteria have been explored by Polasky et al. (2011) in a seminal article on future environmental management. These lines of attack are i) The Thresholds Approach; ii) Scenario Planning; and iii) Resilience Thinking.

The Thresholds Approach

Complex adaptive systems usually possess multiple basins of attraction (Finnigan, this

volume), which (to mix a metaphor) act as islands of stability — sometimes veritable continents. The thresholds approach ignores these relatively stable or slowly changing environments, and focuses instead on potential transitions between them (*cf* Prokopenko, this volume).

These transitions, which are labelled as *critical transitions* or *regime shifts*, arise because the subtle balance between stabilizing negative feedback processes and runaway processes such as positive feedback have reached a point where the runaway processes take over, sometimes in dramatic fashion. Flood plains, and even whole rivers, may dry up (Williams, this volume). Natural populations may suddenly mushroom, or just as suddenly collapse and even disappear entirely (May 1976, 1977). Technical innovations, from the discovery of fire to the development of the personal computer, can transform our lives in a very short space of time. Banking systems may crash, revolutions may break out, whole societies, ecosystems and economies may suddenly burgeon or just as suddenly collapse. All of these are examples of critical transitions within complex systems, emerging directly from the nature of the system itself (Scheffer 2009a; Fisher 2011).

The thresholds approach offers a screen to rule out actions which modelling and other approaches shows offer a high risk of crossing a threshold. At the least, it allows us to rank actions according to the likelihood of such risk. Computer modelling of such risk goes back to the Club of Rome report *The Limits to Growth* (Meadows et al. 1972), whose predictions still largely held good thirty years later, despite the relatively primitive nature of the original model (Turner 2008).

A particularly important application of the thresholds approach lies in the calculation of boundaries for various variables that affect our planetary ecosystem. One pioneering study, published in the prestigious scientific journal *Nature* under the title "A Safe Operating Space for Humanity," (Rockström et al. 2009) provided conservative calculations for nine variables based on contemporary knowledge, and concluded that three (climate change, the nitrogen cycle, and biodiversity) were already close to or (in the case of biodiversity) well beyond the safe limit.

That's the science. The politics, as many despairing environmentalists and other concerned people will know, is quite a different matter. It is a truism that politicians do not understand how science works, but it is an equal truism that most scientists neither understand nor respect the constraints under which politicians operate. These are practical communication issues that need crucially to be resolved (Fisher 2012; Leach, this volume) before *any* sensible approach to decision-making in the world's complex socio-economic-ecological environment can be undertaken.

Scenario Planning

Scenario planning is science fiction for the real world. It conceptualizes the future by inventing plausible stories, supported by data and modelling, about how situations might evolve under different conditions if particular human decisions are made and acted on. By examining this range of potential futures, decision-makers can assess the robustness of alternative policies, and also hedge against "worst-case" scenarios.

Two contrasting cases (see Polasky et al. 2011) illustrate the potential value of this approach to decision-making in complex situations. In the early 1970s, with oil prices

low and predicted to remain so, Shell nevertheless considered scenarios where a consortium of oil-producing countries limited production to drive oil prices upwards. As a result, the company changed its strategy for refining and shipping oil. It was then able to adapt more rapidly than its competitors when the scenario became reality in the mid-1970s, and rapidly rose to become the second-largest oil company in the world.

By contrast, IBM failed to use scenario planning in the 1980s when predicting the market for personal computers, and withdrew from a market that became more than a hundred times larger than its forecasts.

The weaknesses of scenario planning lie in the difficulty of choosing among a large number of possible scenarios and in assessing the likelihood that alternative scenarios (with different degrees of seriousness) will actually arise. Even so, as the above examples illustrate (see also Simpson, this volume), it can be useful as one of a portfolio of decision-making processes, and has the additional advantage that the stories that it tells can readily be understood by non-technical decision-makers. Perhaps this is why it finds such favour with government committees concerned with disaster planning.

Resilience Thinking

One of the key indicators for the nearness of a critical transition in a complex social, economic or ecological system is a decrease in resilience—that is, a decreasing ability of the system to recover from small perturbations (Scheffer 2009b).

Resilience thinking (Fisher 2016) focuses on promoting awareness of such warning signals, and also on the conservation of key processes so that the system is able to adapt most readily to sudden change if and when it arises.

The obvious problem here is that a very wide range of problems and options needs to be considered to make such planning possible. True interdisciplinarity is the key here—not just scientific interdisciplinarity, but social, economic and even political interdisciplinarity.

A second, major problem is that the time scale of most of the warning signs is unfortunately as short if not shorter than the current time-scale of many decision-making processes in society (Biggs et al. 2009), although careful analysis (Dakos et al. 2015) has shown that reliable prediction may nevertheless be possible under the right circumstances.

The difficult, confronting conclusion is that successful planning for our complex future will almost surely require a totally different approach to managing our affairs, and will need new, rapidly adaptive ways of decision-making, such as using the rapid response time of the Internet as a part of the information-collating and decision-making processes (Galaz et al. 2010). Developing such an approach may require a measure of understanding and good will that is currently beyond us, but the decision criteria above (especially if used in combination) at least suggest that there is light at the end of the tunnel, even if there is a train coming the other way.

iii) Changing the System

"A centipede was happy—quite!
Until a toad in fun
Said, "Pray, which leg moves after which?"
This raised her doubts to such a pitch,
She fell exhausted in the ditch
Not knowing how to run."

Katherine Craster "Pinafore Poems" (1871)

The plain fact is that complex systems, from our bodies to our social-economic-ecological environment, run reasonably well on their own self-generated rules for most of the time. We may not understand *how* they work, but there is a case for arguing that our attempts to understand and change them can only too easily make things more difficult (Finnigan, this volume).

It is a case that has some support in the fields of economics, ecology and society. Planned economies have a dismal record. Attempts to alter ecological systems for our own benefit have sometimes proved disastrous, as when the Hawaiian cane toad was introduced into Australia in an attempt to control the destructive cane beetle, only to prove itself to be the much more destructive agent itself. Attempts to set up planned utopian societies have almost inevitably ended in failure.

If we can't easily foresee the consequences of our actions in complex situations, should we not simply leave the situation alone and watch what develops? The argument, cast in mathematical form by Wolfram (1984), has a beguiling appeal, especially if it appears that any action we take has an equal chance of improving the situation or making it worse, and that there is nothing else that we can do.

But often there is something else that we can do, in principle at least. We can change the system.

Predicting change and evolution in even the simplest of networks is fraught with difficulty. The simplest network consists of just two hubs connected by one or more links. Even here prediction and decision-making is not a simple process. If the two hubs represent the partners in a relationship, and one partner responds badly to something that the other has said, there may be a positive feedback process where an argument rapidly develops, or a negative feedback process where the first person apologizes and calms the situation down. The "decision" of whether to use the first or second strategy can depend on other links between the partners, such as previous history. If we make the network bigger, to include (say) the first partner's mother, the relationship with the mother may influence the way that things develop.

When it comes to the many extended networks in which we are all involved, multiple links can influence our decisions and behavior. Our actions in a two-way partnership, for example, may be influenced by the actions of a bank manager at a distant hub, whose decisions about a mortgage application may cause anxiety in a relationship and increase the possibility of arguments.

All of this is blindingly obvious, as is the fact that with increasing complexity the evolution of a complex adaptive network becomes increasingly difficult to predict. What is less obvious is that we can, in principle, control at least some aspects of the resilience and stability of the network by deliberately altering the nature and strength of the links, and removing or adding appropriate hubs.

We are only at the beginning of understanding how this may be done. It is, however, worth making several key points:

1) As pointed out by ecologist Robert May and banking strategist Andrew Haldane in a seminal paper (2011), modular configurations can in principle prevent contagion (from the outbreak of a disease to the collapse of a bank or an economy) from infecting a whole network (be it an ecological network, a social network or a banking network). "By

limiting the potential for cascades," they say "modularity protects the systemic resilience of both natural and constructed networks."

"Modularity" in this context means breaking the system into blocks (sub-networks), with only limited links between the blocks. The problem here is to get economists, ecologists and others to understand the properties of networks, and in particular that those which are most efficient in the short term (sometimes through being non-modular) may carry within their very structure the seeds of long-term instability.

2) Modularity seems like a sound principle, but one must be aware that it is only applicable to certain types of network. It is difficult to visualize, for example, how the concept may be applied to the nested networks that are common in economics, ecology and society.

Nested networks also pose another problem. Paradoxically, the strongest contributors to the stability and persistence of the network as a whole are also those that are most vulnerable to extinction (Saavedra et al. 2011). This stricture applies equally to ecological networks and networks of business firms. Before we start messing around with such networks, we need to know more about why this paradoxical effect occurs.

3) Finally, our understanding of how signals and other effects are propagated through networks (especially those that contain a human element) is by no means complete (Barabási 2003). Why do some YouTube videos, for example, "go viral", while others attract virtually no attention? How do the activities and habits of individuals affect the behavior of the network as a whole? Do people who appear as hubs with many connections really act as "opinion-formers" (the answer seems to be "no" (Watts 2007))? Why and how do some types of information and influence appear to travel through social networks in "bursts" (Karsai et al. 2011)?

These questions were posed just a few years ago and, as the papers from this forum show, we are only just beginning to understand how these processes work. We can only hope that some answers will emerge in time to be useful in solving the serious problems such as climate change (Spies, this volume) and food security (Simpson, this volume) that confront us as we attempt to make the best decisions in an increasingly complex world.

Envoi

There are many important topics that it has not been possible to include in this brief overview. One, implicit in many of the papers from this forum, is the role of game theory, which analyses the paradoxes and problems that come in when a strategy of cooperation would lead to the best outcome for all concerned, but where each party is tempted to try for a better outcome for itself, only to become trapped by its own greed in an inferior situation, like a lobster caught in a pot (von Neumann & Morgenstern 1944; Fisher 2008).

The other major topic that I have not mentioned explicitly is the nature and perception of risk, which enters into many of the decisions that we must make in the face of complexity. This whole article could have been written from that perspective, and may even have been better for it. But it would have become much more mathematical, and others (e.g. Dekkers 2011) have tackled the subject much better than I could have. So I wasn't willing to take the risk.

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Society as a complex system: can we find a safe and just operating space for humanity?

John J. Finnigan

Australian National University, Research School of Biology; CSIRO Oceans and Atmosphere

Corresponding author.
Email: john.finnigan@csiro.au

Abstract

The concept of "planetary boundaries" that surround a "safe and just operating space" for humankind is a powerful framing of the problems of global sustainability but implies that we can describe the dynamics of the human-earth system. After defining complex systems in general and introducing the idea of system attractors, we assert that the human-earth system can be understood as a complex system with a set of societal attractors. We show that at a high level its dynamics have been controlled by a powerful 'Malthusian' attractor through most of history but that it left that state in the Industrial Revolution. We go on to model the post-industrial world as a dynamical system with population, economic output, societal state and impact on the biosphere as state variables. A novel aspect of this model is its overt incorporation of political dynamics. Finally, we ask whether this system has an attractor that constitutes a safe and just space for humanity in the future.

Introduction

As we head towards levels of human population and economic activity that the world has never before seen, understanding what is required to ensure the sustainability of human society is now recognized as the most pressing scientific and social issue of our time. In this paper we approach this issue by conceptualizing the human-earth system, that is, the intersection of society and the biophysical workings of the planet, as a complex, globally connected system. This approach assumes that questions of global sustainability require global answers. The United Nations recognized this basic fact over three decades ago and the UN's Sustainable Development Goals (SDGs), which are intended to be achieved by 2030, are the latest set of targets to which member nations have committed in the quest for a socially, economically and environmentally sustainable world. Achieving the SDGs will be challenging for two reasons. First, while the SDGs address individual areas of concern such as poverty, hunger, education and health (and 13 others), these are all reflections of an underlying dynamical system and are connected at a deep level so that achieving one goal may aid or thwart another; and, second, because the current trajectory of the human-earth system seems to be heading in a different direction to some of the most important of these goals.

A different more 'scientific' approach to the question of global sustainability was proposed in 2009 when Johann Rockström and colleagues proposed a framing of global sustainability through a set of Planetary Boundaries (Rockström et al., 2009; Steffen et al., 2015). They defined the extremely stable late Holocene climate of the last 10,000 years as demonstrably a safe operating space for

humanity, because all human civilizations arose in this period. They catalogued biophysical processes that could tip the planet out of this state and defined safe, uncertain and high-risk levels for a minimal set of nine controlling variables. Transgressing the high-risk boundaries poses clear and present dangers for the biospheric services that society depends upon. In their 2015 update they calculated that two indicators, namely loss of genetic diversity and perturbations to the global phosphorus and nitrogen cycles, had entered the high-risk zone while climate and land system change were heading inexorably towards it (see Figure 3 in Steffen et al. 2015).

While controversial, the Planetary Boundaries approach had its intended effect of reframing the debate on biophysical sustainability. However, in an influential paper for Oxfam in 2012, Kate Raworth pointed out that a Safe Operating Space for humanity must have social dimensions also, and that for a safe and *just* operating space (SJOS), we need to respect both sets of boundaries (Raworth, 2012). Raworth insisted that we must live on the 'doughnut' bounded on one side by the biophysical boundaries and on the other by her social boundaries (see Figure 1 in Raworth, 2012). Raworth's eleven boundaries included qualities like gender equality, social equity, jobs, voice and resilience. The problem of using such attributes in the same way as the physical boundaries of Rockström et al. soon becomes apparent, however. The physical boundaries corresponded to variables in a mathematical description of the coupled biophysical dynamics of the planet. Raworth's social boundaries in contrast were not related to any underlying mathematical description of social wellbeing and, furthermore, they were incommensurate in the sense of a hierarchy of needs, such as that of Maslow (Maslow, 1943), which starts from the basic physiological requirements of life but moves up through safety, love and belonging, esteem and self-actualization. Raworth's boundaries were notional threshold values of quantities that belonged to different levels of Maslow's hierarchy.

Nevertheless, the point that a SJOS for humanity has both social and biophysical dimensions is well taken, as is the need to describe the human-earth system mathematically as a dynamical system, if we are to apply the planetary boundaries approach in a rational way. So let's start again and see what a dynamical systems description of the human-earth system would look like. The theme of this symposium is society as a complex system so the first question we need to ask is why we would describe the human-earth system as a complex system, but even before that we need to understand what we mean by a complex system.

Complex Systems

The literature abounds with definitions of complex systems, for example, that they have many interacting parts, feedback loops, strongly nonlinear behaviour, exhibit learning, and so on. However, when forced to decide what separates a complex system from one that is 'merely' fiendishly complicated, we find that complex systems have just two essential attributes. One is emergence: the behaviour of the whole system is qualitatively different from the sum of its parts. The second is self-organization: the system tends spontaneously to some level of ordered behaviour.

Emergent properties and emergent behaviour means that many underlying microstates of the system correspond to the same

emergent macro-state. We see this in physics, where atoms can arrange themselves in many different ways to form crystals, such as in the crystal patterns of snowflakes, or in the biological world, where termite or ant colonies or bees in hives, for example, have many interacting units (the insects), whose behaviour is much simpler than that of the whole colony. Bees, of course are complex organisms in themselves, but the bee colony behaves as it does because many worker bees, a few drones and the queen act in interchangeable ways to produce the emergent property of the beehive. The hive is a super organism that can construct a home, seek food, reproduce the next generation, feed the queen and swarm.

Now move up some levels to human society. As humans evolved from earlier primates, basic social systems such as family groups and bands emerged to exploit the evolutionary advantages of cooperation. More complex organizations such as tribes achieved the added advantages of larger groups and then, as society developed, we saw the creation of even more complex political arrangements such as kingdoms and empires. The social technologies necessary to enable these larger groupings to have a stable existence, such as money, economies, religions, patriarchal and matriarchal traditions and systems of government, were all emergent properties of the interaction of many people living as a society.

Self-organization is somewhat different. At one level it has a whiff of Bergson's 'elan vital' but really it just means that there are some preferred states that the system would like to be in and that its internal workings will drive it towards these configurations. Physical systems often seek configurations with the lowest potential energy. In the previous example of snowflakes, it takes extra energy to move the system of interacting water molecules out of their low-energy crystal configurations. Add heat to the snowflakes though and they become just a bunch of disordered colliding water molecules.

Considering human society again, physical infrastructure such as villages, towns and cities are attractors in the case of groups of people producing a surplus of food, which describes humankind after the Neolithic revolution, the invention of farming and pastoralism. Villages, towns and cities solve the problem of how to live optimally on a landscape. They provide human society with clear advantages, such as defence against predation, cooperation for tasks that are beyond the capacity of small groups and development of and access to specialists. We can think of what might be called 'the great paired experiment', the development of civilization in the old and new worlds. Humans went to the Americas in Palaeolithic times, 12,000 years ago at the latest, when human society consisted only of hunter gatherer bands. They then developed societies on both sides of the Atlantic completely independently. But when Europeans went to the Americas in the 15th century, they found political systems, tribes, empires, cities, economies and religions, which were exact parallels of what they had left behind in Europe. These societal arrangements developed completely independently and so are evidently fundamental properties of human society once people start to interact in larger and larger groups. They are attractors for human society.

The concept of attractors is an important complement to that of emergence and self-organisation. If many microstates of a system correspond to just a few emergent macro

states, we can infer that these macro states are attractors. We could start the system off in many different initial configurations and it will self-organize or 'be attracted' to one or another of the limited number of macrostates. Many different arrangements of atoms organize themselves in just a few snowflake patterns as the temperature drops below freezing. Different numbers of individual bees arrange themselves in functioning hives, and different races of humans eventually develop cities, religions, economies and so on from scratch.

Attractors can be illustrated most directly using the state space visualization of system behaviour. The state space is defined by axes that reflect the defining properties of the system so that every point in the space is a potential state of the system. As time progresses, the actual system behaviour traces a trajectory through this space and, when an attractor exists, the trajectory is drawn to this restricted region of the state space and thereafter cannot escape it. For a more detailed treatment of this important point as well as an illustration of the power of the geometric approach to analysing complex systems, the reader is referred to Appendix 1.

Understanding human history using the concept of attractors

If one had to describe the history of the world from the emergence of farming until now, it is possible to do so succinctly (or glibly) in two statements: for the first twelve thousand years nothing happened and then, in the last 200 years everything happened. Figure 1 illustrates these statements by indicating the emergence of physical and social technologies on a graph of global population for the last 11,000 years. Clearly evident on this graph is the very slow change in population over most of this period and the concomitant slow emergence of different physical and social technologies and then, suddenly, with the arrival of the Industrial Revolution[1] 200 years ago, we see a step change in the growth rate of population and a similar quantum leap in the emergence of advanced technologies.

Looking at population and wealth together in Figure 2 confirms the existence of two different behavioural domains. Global population and GDP grow almost in lockstep and at a very slow rate until the Industrial Revolution and then increasingly rapidly up to today. Global wealth (approximated by estimated GDP) grows even faster than population so, if we divide the two and look at wealth per person, (approximated by GDP per-capita), we see that in the last 200 years it has grown even faster than the population.

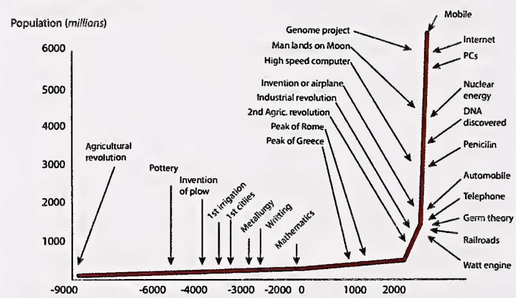

Figure 1. Growth of world population and the history of technology. Source: Milken Institute, Robert Fogel, Univ. of Chicago.

Contrast this with earlier millennia. A peasant in China in 1000 BC was just as well off as a peasant in Europe in 1000 AD. Basically, for the mass of humanity, things stayed the same for most of those past twelve thousand years. To be sure, great empires emerged,

[1] We use the familiar term Industrial Revolution as a generic label for the rapid transformation not only in industrial activity but in food production, population, urbanisation and international inequality that began 200 years ago in Western Europe (Clark, 2007).

great art was made, great cities rose and fell and a very few people were extremely wealthy. For the majority of people, life didn't change.

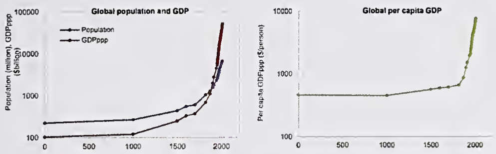

Figure 2. Left panel: estimates of global population and global aggregate gross domestic product (GDP) from AD 1 to 2008. GDP is in International Gheary-Khamis dollars, a time-independent unit that approximates the purchasing power of $US1 dollar in 2000. Right panel: per-capita GDP over the same period. Source: Figures from Raupach et al. (2012); data from Maddison (2010).

Adopting the geometric description of system state (Appendix 1) and choosing axes of population and per-capita wealth to define the state space of the human-earth system, through most of these past millennia its trajectory stayed on an attractor with low values of both. If we extend the state space by adding an axis to denote human impact on the global biosphere, the trajectory stayed close to the origin of that axis too. In Figure 3 we illustrate this state of affairs schematically but also show that, starting at the Industrial Revolution, the trajectory has moved rapidly away from the origin, reaching by 2015 a global population around 7Bn, globally averaged per-capita income of around U$15,000 pa and major impact on the biosphere, denoted in Figure 3 through the exceeding of several biophysical planetary boundaries. This figure prompts the obvious question: what was the nature of the attractor that kept human population, wealth and biospheric impact so small for so very long and what eventually allowed them to escape this attractor?

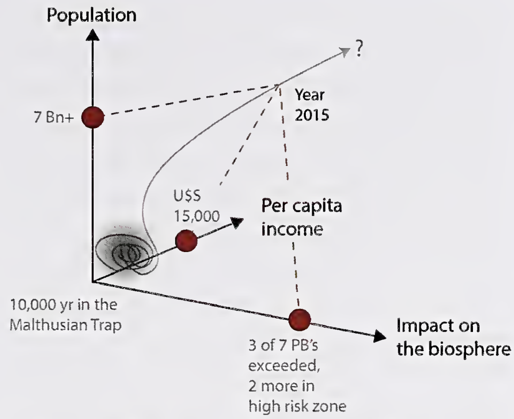

Figure 3. Trajectory of the human-earth system in a 3D state space of population, income per-capita and biospheric impact.

The Malthusian Attractor

Thomas Robert Malthus was an English clergyman of the 18th century. His famous book, *An Essay on the Principle of Population*, ironically written in the opening years of the Industrial Revolution, explained why people actually stayed poor — basically, why the many remained trapped in poverty while the rich few remained rich (Malthus, 1798). In its simplest form, the elements of the Malthusian attractor (sometimes called the Malthusian Trap) are threefold: first, that the birth rate, or fertility, increases with per-capita material income[2]; second, that the death rate, mortality, decreases with per-capita material income; and, third, that per-capita material income decreases with population. This third principle implies that everyone is effectively sharing a fixed amount of resources, so the more people there are, the less any one person has. More fundamentally, it is a consequence of the law of diminishing returns which was introduced into economics by David Ricardo at about

[2] The *material income* refers to the total amount of goods and services that a person consumes.

the same time as Malthus was writing. The Malthusian economy is also the economy of the natural world and applies equally to pre-industrial humanity in the large or to a herd of wildebeest grazing the savannah. These three principles are illustrated schematically in Figure 4 after Clark (2007).

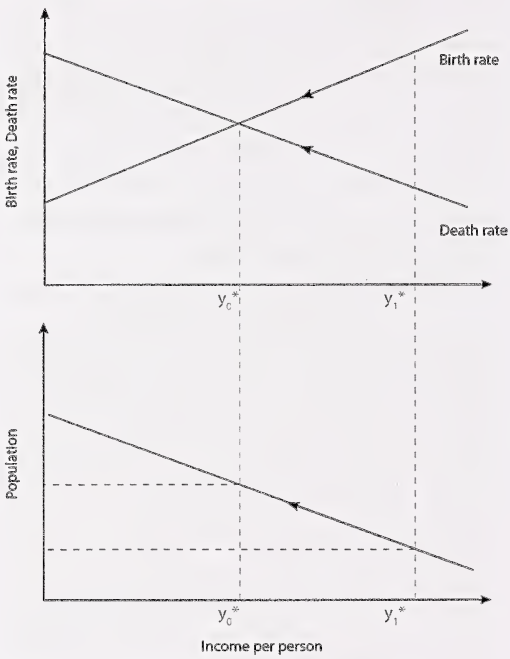

Figure 4. The Malthusian attractor.

When the population is in steady state, which on a global scale it roughly was through the 12 millennia between the agricultural and industrial revolutions (10,000BCE–1800AD), at least compared with the two centuries since then, the birth rate must equal the death rate. The point, where the birth and death rate curves intersect, defines the 'subsistence income'. The actual relationships between birth and death rates were different for different societies with different norms, expectations and practices as well as material environments but together, the birth and death rate 'schedules' define the subsistence income. At any subsistence income the curve relating income to population defines the population that can be supported at that income. This is a function of the technology available, so this third curve is called the technology schedule.

As explained by Clark (2007) or Lee and Schofield (1981) this attractor always draws the population back to the subsistence income point. An increase in the birth rate over the death rate for whatever reason will increase population in the short term but then the resulting fall in income will reduce births and increase deaths until the two are in balance again. A few important points need to be made here. First, the subsistence income is not necessarily a starvation income; it can support a healthy and relatively comfortable (by pre- industrial standards) lifestyle. Second, the subsistence income is entirely determined by the birth and death rate schedules. For example, the result of increasing the birth rate at a given income level while leaving the death rate-income relationship the same is that the population grows and everyone gets poorer. Third, improvements in technology, which shift the technology schedule to the right, are entirely swallowed up by increased population without changing the subsistence income. As a consequence, in pre-industrial times the only way the income of the mass of the population could be improved was by increasing the death rate and reducing population. This proposition is illustrated in Figure 10.1 in Clark (2007, page 194) by the almost doubling of the income of English workers between 1340 and 1450. In 1348, the arrival of bubonic plague killed up to 30% of the population and, with essentially stagnant technological change, the result was

a major improvement in the material income of the survivors. The reader is referred to Clark (2007) or Lee and Schofield (1981) for a fuller discussion of the dynamics of the Malthusian attractor.

As is indicated in Figure 1, the effectiveness of material and social technologies that controlled how much impact society could have on the biosphere increased only very slowly for most of the long millennia after the invention of farming and pastoralism. As a result, while societies locally could destroy the ecosystems upon which they depended, for example, by salinizing soil through irrigation, which was a major cause of the demise of early city states in southern Mesopotamia, in total humanity's impact on the earth was slight. Hence in Figure 3, we show the trajectory moving on an attractor close to the origin of a state space defined by population, income and biospheric impact. However, in Figure 10.1 of Clark (2007 page 194) we see that something profound happened in the mid 1700s, which broke the inverse relationship between population and income. This change, as we shall see, involved rapid synergistic development in both material and social technologies, leading to a transformation not only of humanity's material condition but critically and essentially, to its social organization.

Towards a dynamical systems description of the industrial and post-industrial world

We are going to propose here that we need a minimum of four variables to describe the state space of the post-industrial human-earth system in a way that allows us to understand the basic dynamics that control the system trajectory. These variables are population, economic output, the state of the biosphere, and societal state. One of these, population, is as we have just seen an essential variable in the Malthusian attractor. Economic output is related to material income and in pre-industrial times was practically the same thing. The state of the biosphere is interchangeable with biospheric impact. But the new variable: societal state, refers to the social and political organizing principles, which, before 1800, saw most of humanity ruled by autocratic elites in large tribes, kingdoms, empires, or city states. The changes in societal state, which began with the Industrial Revolution, have shaped the modern world as profoundly as the other three state variables. Let us unpick the interdependencies of these four state variables to see what a dynamical system description of the modern world looks like.

Population

World population seems set to stabilize at levels of 9–11Bn by the end of this century (UN, Department of Economic and Social Affairs, Population Division, 2013). The mechanism of stabilization is the 'demographic transition', a process whereby an increase in life expectancy, particularly a drop in child mortality, is followed in a generation or two by a fall in birth rates (Livi-Bacci, 2012). A range of factors links these two processes. As the Industrial Revolution progressed, by the mid to late 1800s improved sanitation and other advances in cities reduced the likelihood of early death, so that the need for living children as social security for aging parents did not depend on having a large family. At the same time, there was an extra financial burden associated with raising children in an urban industrial set-

ting, where they could not contribute to family incomes until they were much older than in rural settings. These factors provided strong Darwinian forces driving smaller families and population stabilization, which are clearly evident in the developing world today (Dye, 2008). Other factors such as female emancipation, education and contraception all played roles later in the demographic transition. Since WWII, as globalization has caused worldwide dissemination of medical and social advances originally confined to the developed nations, we are now seeing a demographic transition in the developing world while the population of the developed world is now stabilized or declining.

The mechanisms that enable the demographic transition implicitly require significant increases in per-capita wealth or income, and a robust relationship appears to exist between per-capita income and fertility and mortality and has done so over the last 200 years and across different cultures and countries today (Figures 5 & 6). At incomes around U$200 per annum, TFR values are as high as 7 or 8 but at incomes around U$5000, TFR has dropped to the replacement value of 2.1, with some cultural variations around this. Complementary to this, life expectancy reaches around 70 years at incomes of U$5000 and flattens thereafter. Globally, TFR values have now reached about 2.3-2.4 but are still strongly skewed to higher values in the poorest countries, particularly sub-Saharan Africa (UN, Department of Economic and Social Affairs, Population Division, 2013). Nevertheless, global population growth in the future is projected to be primarily due to population momentum, the fact that more generations will be alive and childbearing simultaneously as longevity increases.

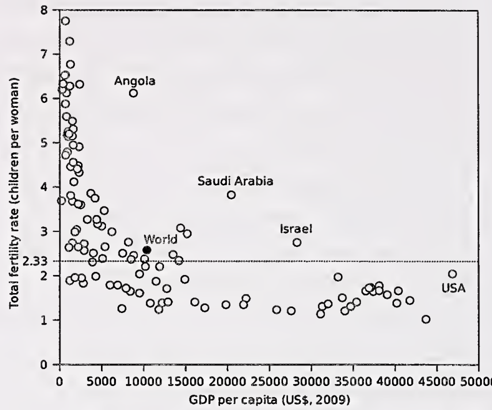

Figure 5. Total fertility rate (TFR) vs GDP per capita. Source: World Bank 2010.

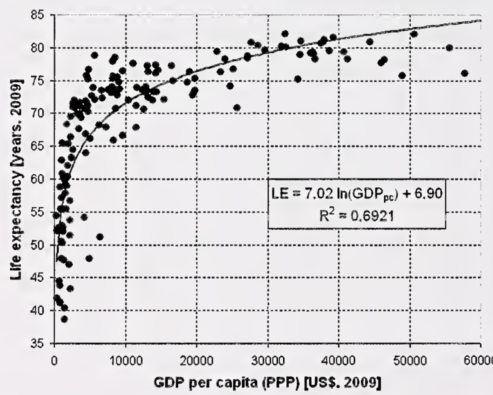

Figure 6. Life expectancy at birth vs GPD per-capita. Source: index mundi website.

Although the relationship between per-capita income (usually approximated by GDP/capita) and TFR or mortality is clear, the underlying mechanisms are complex and involve processes that include education (especially education for females), improved health services and urbanization. Urbanization in turn is correlated with economic growth and higher incomes but then exerts the Darwinian pressures for smaller families discussed earlier. Completing the demographic transition to stabilize and then reduce population thus implies an increase in global GDP, continuing urbanisation

and a reduction in within-country income inequality so that the GDP rise can affect choices of family size.

Economic output

Global economic growth is required both to effect the demographic transition and also to set up the conditions for the political evolution of nations from states where basic human rights are not guaranteed to those where they are: in effect to allow them to make a transition to what Karl Popper, in his landmark book, called 'The Open Society' (Popper et al., 1945). We make the normative assumption here that to meet the kind of desiderata that Raworth (2012) suggests are necessary to have a safe and just operating space for humanity, a political structure corresponding to Popper's Open Society is necessary. In the next section, we will describe such societies as Open Access Orders. A certain minimum level of economic output is required to make this transition. Unlike the Malthusian economy described earlier, where per-capita economic growth is primarily limited by inputs of land and capital, in an industrial and post-industrial economy, three quarters of per-capita economic output devolves from gains in the efficiency with which inputs are converted to outputs (Clark, 2007). In modern societies, economic growth is a synergistic process, as wealth creation occurs much more rapidly in open societies where all can participate productively in the economy and the power of innovation and competition of ideas can be freely exerted (North et al., 2009).

Although we cannot develop this theme here, it is important to note that the second law of thermodynamics implies that increasingly complex social, economic and industrial structures require greater throughput (dissipation) of energy than simpler systems. Some recent work has strongly suggested that the industrial and post-industrial world system that was sparked by the Industrial Revolution, would have remained stillborn without access to fossil fuel energy, which exceeded earlier energy sources (wind, water and muscle) by orders of magnitude (Liska and Heier, 2013). This new energy source together with increased rates of innovation during the Industrial Revolution was critical in breaking the inverse relationship between population and material income per-capita. A third critical factor in leaving the Malthusian technology schedule was the concentration of human capital in cities. This catalysed innovation as well as increasing manufacturing efficiency, and it also played a crucial role in social transformation, as we see next.

Societal dynamics

North et al. (2009) describe three phases or 'orders' in the development of human social organization. The first, called the 'foraging order', describes the organization of hunter-gatherer bands and has little relevance today. The second they term 'the natural state' or 'limited access order', which has existed since the Neolithic revolution and still persists in most countries today. Fukayama (2012, 2015) refers to the natural state as the patrimonial state. The third is 'the open access order', a mode of social organization that characterizes the kind of advanced developed countries where Raworth's desiderata are generally obeyed and corresponds to Popper's Open Society. Fukayama calls these liberal democracies.

The distinguishing characteristic of the natural state is that all power, influence, access to legal recourse, and ability to take part in political or economic life depends on personal relationships and status — who is related to whom, who supports whom — or

on one's personal prowess, reputation or popularity. No institutions that operate in society or economy are admitted except those allowed by a ruling elite. In contrast, in open access orders, recourse to law and political power is completely depersonalized — all are equal before the law. Similarly, any group of citizens can form organizations to contest political power, to promote causes or to operate in the economy.

Obviously, the natural state has evolved considerably through the long Malthusian twilight into modern times and North et al. (2009) distinguish three main levels of natural state: the fragile, the basic, and the mature, and within these levels exist still finer gradations. Mature natural states emerged in Britain, some other European countries and the USA in the 18th and 19th centuries and many (most?) countries in the world are still organized along this model. To paraphrase North et al. (2009), natural states are distinguished by:

1. Slowly growing economies, vulnerable to shocks;
2. Government without the general consent of the governed;
3. Relatively small numbers of organizations;
4. Smaller and more centralized governments;
5. Social relationships organized predominantly along personal lines, including privileges, social hierarchies, laws enforced unequally, insecure property rights, and a pervasive sense that not all individuals were created or are equal.

The transition from mature natural states to open access orders occurred in a few countries such as Britain, France and the USA in the mid to late 19th century. Paraphrasing North et al. (2009) again, open access orders are characterized by:

1. Political and economic development;
2. Economies that experience positive growth on average;
3. Rich and vibrant civil societies with lots of organizations;
4. Bigger, more decentralized governments;
5. Widespread impersonal social relationships, including rule of law, secure property rights, fairness and equality.

As intimated above, stark differences in the number of organizations and size of government as a fraction of national income serve to distinguish the twenty or so countries that today clearly exhibit open access orders from those that remain natural states (North et al., 2009).

An essential link between the growth of per-capita economic productivity and consequent national wealth that occurred in the Industrial Revolution and the transition to open access societies has been highlighted by Fukayama (2015). Prior to the industrial age, society could be broadly divided into land-owning elites and a much larger agrarian servile class. In the Industrial Revolution, centralization of manufacturing saw a step increase in urbanization and relative depopulation of the countryside, while the economic explosion created new classes: the middle classes or bourgeoisie and the industrial working class. Relaxation of the ties of the older social order in the new cities allowed these new classes to organize themselves and to demand participation in the political process. In particular, acceptance of new ideas about individual rights and what was acceptable in social organization, such as the 'Declaration of the Rights of Man and the Citizen' by Jefferson and Lafayette

became widely shared in the new urban societies and informed these demands.

In this paper, we will take the existence of an open access order in society as the signifier of a social safe operating space. Based on the characteristics of this order that are listed above, this allows us to make direct links between social organization and economic output, which in turn is linked to impacts on the biosphere. Similarly, social organization can be linked formally to innovation and the technology schedule and also to population dynamics, particularly the dynamics of post-Malthusian demographic transitions.

However, if we want to use social order as a variable in a dynamical systems description (presumably as a coarsely resolved ordinal variable with the foraging order denoted as, say 1, the fragile, basic and mature limited access orders as 2, 3, 4, respectively and the open access order as 5), we need a model of how societies transition from natural states to open access orders, a model that is driven by the other state variables. For this we adopt the theory of Acemoglu and Robinson (2007), who showed that intolerance of excessive income or wealth inequality by the majority can force ruling elites to concede *de jure* power so as to avoid violent revolution. This indeed was the key mechanism of transition from mature natural states to open access orders in early adaptors like Britain and the USA. However, if de jure power is not transferred in the face of the rejection of inequality by the mass of society, the result is violent revolution or the maintenance of repressive mature natural orders. This treatment of societal state as a progression from the most primitive levels of organization to modern liberal democracies — and which depends on other state variables, particularly the absolute level of wealth and its distribution — is perhaps the most novel aspect of our approach to conceptualizing the human-earth system.

Impact on the biosphere

The impact of economic activity on the biosphere is now clear and profound. Climate change is the most prominent manifestation of this, but other factors such as ocean acidification, over-extraction from terrestrial aquifers, loss of biodiversity and the altering of oceanic and terrestrial trophic structures will have irreversible impacts on the provision of the ecosystem services that we rely on for food and water. These problems are encapsulated in the biophysical Planetary Boundaries analyses of Rockström et al. (2009) and Steffen et al. (2015) but they also play immediately into the provision of safe and just operating spaces, as the impacts of environmental degradation are greatest on the poorest people and countries.

Producing energy to drive the economy and the impact of this on the climate and biosphere poses a serious challenge. Maintaining the required societal complexity to bring a world population of 9–11Bn to a safe and just operating space requires increased energy flows. Provision of this through fossil fuels is impossible, if we are to avoid grave biophysical consequences. Fortunately, alternative renewable energy technologies exist at the price of economic transitions, which may be politically difficult but could accelerate rather than reduce economic growth rates, at least as measured by GDP and employment. Provision of food and water for 9–11Bn is possible but may require a global reassessment of what is meant by sustainability. Some things we see as valuable parts of our planetary estate may have to be abandoned to bring humanity through the population

bulge safely. Making the choices that will keep us on a safe trajectory depend on social dynamics.

A model of the Human-Earth System

In this section we will illustrate the links and feedbacks between the four state variables: population, economic output, societal state, and biospheric impact. As we do so, the important role played by the linking processes, energy production, urbanization and wealth inequality will become apparent. We begin with the key processes controlling population illustrated in Figure 7.

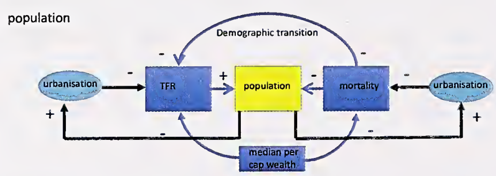

Figure 7. Population subsystem.

In all of the following diagrams the arrows indicate the direction of influence and the plus (or minus) sign by the arrowhead tells us whether an increase in the variable or process from which the arrow starts leads to an increase (or decrease) in the target variable. Population is the result of the balance between TFR and mortality integrated back through time. The demographic transition is the dominant feedback, so that a decrease in mortality leads to a decrease in TFR. An increase in per-capita wealth, transmitted down to family level either directly or through increased state services, is approximated by median GDP per-capita and decreases both TFR and mortality. Finally, an increase in population eventually can be assumed to increase urbanization, which has a damping influence on both TFR and mortality (Dye, 2008).

In Figure 8 we look at economic output. At the most basic level, population increases economic output, Y through the fundamental relationship,

$$Y = A^{*}\boldsymbol{F}[P, K, L] \tag{1}$$

where L is land (or resources), K is capital and P is labour, while A is the efficiency with which these three inputs are transformed into output through the functional interrelationship denoted by $\boldsymbol{F}$.

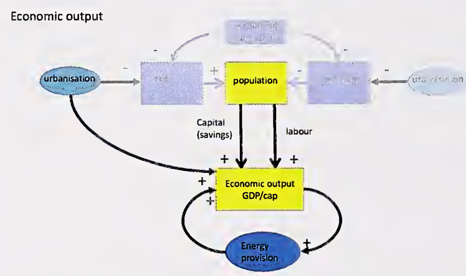

Figure 8. Economic subsystem.

As well as its labour, the savings of the population are also available to be invested into the economy so population increases output both directly and indirectly. As we stated above, concentration of manufacturing in cities increased efficiency and also innovation, while the transition to an open access order also unleashes the power of innovation and novelty on economic activity. Finally, an economy requires power, so a part of economic activity is power generation, which forms a positive feedback loop in the system.

The key links in the societal state subsystem are shown in Figure 9. As well as the positive influence of an improvement in societal state on economic output, we have seen that a certain level of wealth must be generated to first kick society out of the Malthusian attractor and then to maintain a transition towards an Open Access Order.

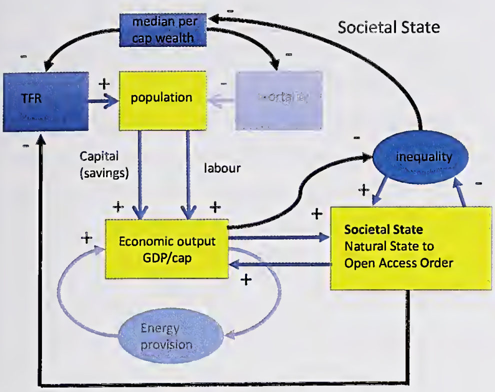

Figure 9. Social subsystem.

We have described the mechanism by which an increase in inequality can paradoxically, trigger a transition towards more democracy, and correspondingly an improvement in societal state reduces inequality. Inequality is a critical filter through which economic output passes to be converted to our measure of wealth inequality—median GDP per-capita—which then influences TFR and mortality directly. Finally, societal state affects TFR directly via cultural norms and expectations, with less developed societies having higher TFR's when corrected for all other influences (Livi Bacca, 2012).

Links and feedbacks for the last state variable, biospheric impact are diagrammed in Figure 10. The experience of the last 12,000 years is that the processes of economic output and energy provision generally degrade the environment.

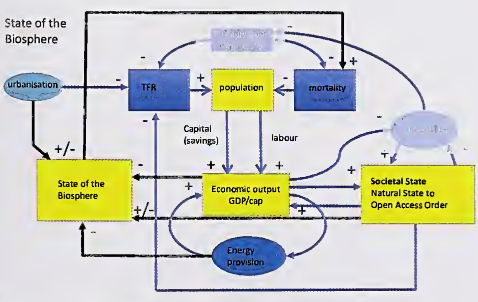

Figure 10. Biospheric subsystem.

Societal state can have either a positive or a negative influence on the biosphere, depending on whether the ruling ideas of society privilege exploitation or nurturing of the environment. Urbanization too can have either negative and positive consequences. Negative impacts come through appropriating often productive land or introducing concentrated effluent streams into the local environments of cities, for example, the dead zone extending from the mouth of the Mississippi into Gulf of Mexico. Positive impacts come because concentrating human habitation vastly reduces the amount of land the same number of people would require, if they were rural dwellers. Finally, a degraded environment will necessarily increase mortality, particularly of the poorest and most vulnerable.

These four systems are brought together in Figure 11, which prompts the immediate observation that the processes we know least about, to the extent that most models of the human-earth system do not even try to include them, are the socially determined ones. Their links are coloured red in Figure 11. Parameterizing the functional relationships between the state variables and the intermediate processes and factors illustrated in Figure 11 will be the subject of a further paper, which will focus on detailed analysis of the system properties, especially the possibility and nature of stable attractors for some parameter values.

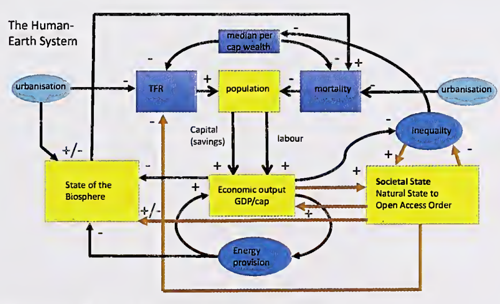

Figure 11. Human-earth system.

Discussion: is arriving at a safe and just operating space possible?

Even without the formal analysis just alluded to, exposing the dominant interrelationships of the processes controlling evolution of the four state variables suggests some conclusions that are not so obvious, if the variables are considered separately. First, there is a direct relationship between per-capita wealth and the drivers of population. As we have seen, this has existed throughout history even in Malthusian times but today it means that projections of a stabilizing then declining global population — a *sine qua non* for a sustainable world — imply very large increases in wealth generation. Generating this wealth requires economic growth, but this will have substantial negative impacts on the biosphere and thence onto mortality and other factors affecting the social dimensions of a safe and just operating space unless serious efforts are made to decouple economic activity and impact. We are seeing currently how difficult this is in the context of climate change, where, despite the fact that decarbonizing energy generation is not only possible but brings with it enormous side benefits, social forces are mounting strong opposition to this transformation.

Unless substantial within- and between-country inequality is also addressed, the amount of wealth generation required to stabilize population will be prohibitive. We have seen that inequality is a driver and reduced inequality a consequence of movement to a higher social order but that the mechanism by which this happens, involving as it does conflict and possible revolution, militates, at least temporarily, against provision of a safe and just operating space for those involved. North et al. (2009) have listed the essential doorstep conditions required so that a transformative social revolution, initiated by inequality, doesn't collapse into anarchy then the re-imposition of autocracy (*vide* the Arab Spring or the collapse of western institutions after the precipitate withdrawal of colonial powers in Africa post WWII). Our analysis together with these (and many other) examples suggests that much more effort needs to put into building institutions in developing countries, if they are to attain the goal of open access societies.

We could detail more of these links but in the spirit of this meeting it is proper instead to close with a more important question: is a safe and just operating space for human society an attractor, given current geopolitical settings, and, if not, what needs to change to make it so? A corollary of this question is whether there are other attractors that human society can end up on that are clearly not safe and just operating spaces and that, once on, would be difficult to escape from?

Conclusion

The human-earth system displays the defining characteristics of a complex system: emergence and self-organization. This implies that its dynamics should have attractors and we can point to a series of social attractors that humanity has been drawn to through most of human history. Once on an attractor, it is difficult to shift the the trajectory of a complex system to a different, more desirable, region of state space without addressing the fundamental relationships governing the system's dynamics. In the case of the human-earth system, many uncoordinated efforts to address separate features of the system, for example, those involved in addressing the UN's SDGs piecemeal, may have little long-term effect or even be self-defeating, if the nature of the major interacting forces governing the trajectory are not understood and policy actions framed with this knowledge.

Acknowledgements

The author would like to acknowledge the many valuable discussions he has had with colleagues but most especially with Dr Luciana Porfirio and Dr David Newth of CSIRO in preparing this manuscript.

Appendix 1 Geometrical representation of complex systems

Along with the properties of emergence and self-organization around attractors, a third important thing to understand about complex systems is that they live somewhere between simplicity and chaos. If we were to plot the complexity of such a system on a graph with "simple" at one side of the x axis and "chaotic" at the other, complex systems live somewhere in the middle (Fig A1). Furthermore, it is the actual nature of self-organization around an attractor in a complex system that allows this balance between order and chaos.

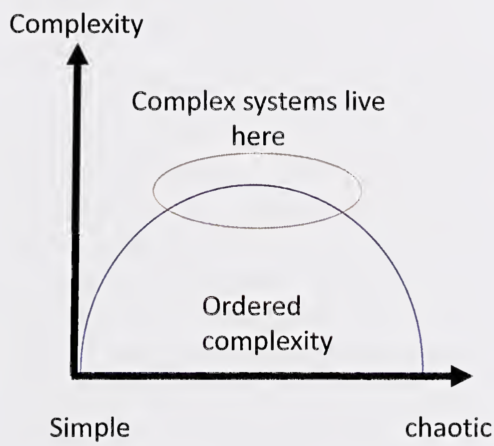

Figure A1. Simplicity vs chaos

In Fig A2 we see a plot of perhaps the most iconic complex attractor, the Lorentz Attractor, which describes convection in a thin layer of fluid (see Tabor, 1989). The Lorentz Attractor can be taken as simple model of the lower atmosphere. It lives in a 3 dimensional 'state' space with axes, X, Y and Z.

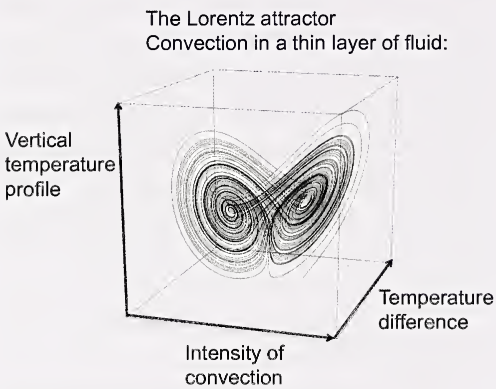

Figure A2. The Lorentz attractor.

Simplifying greatly, X is a measure of the way air temperature changes with height. Y is the intensity of convection, that is, how much movement there is in the atmosphere. Z is the temperature difference between ascending and descending air currents. The 'state' of this simplified model of convection in the atmosphere at any instant of time t is given by the location of a point in the 'state space' spanned by X, Y, Z. As time goes on, the system's state evolves and describes a trajectory which is confined to the surface of the attractor. So the atmospheric state is restricted to a small region of the total 'state space'.

We know from the fact that long-range weather forecasts have high uncertainty that starting a forecast from two close but slightly different atmospheric states will lead to quite different predictions of the weather a week or more hence. The equations governing air movement (of which the Lorentz equations are a simplified version) tell us that our predictions must diverge exponentially with time. Yet we also know that the atmosphere won't spontaneously boil or freeze, so, paradoxically, although the system trajectory must remain in a bounded region of state space, two trajectories that start nearby today must get exponentially far apart if we wait long enough. This paradox is resolved because the Lorentz Attractor is a 'Strange Attractor' with a dimension that isn't an integer. In fact, the Lorentz attractor has a dimension about 2.06. In other words, the surface of the attractor isn't a real surface, it's like millions (actually an infinite number of) onion skins, so two trajectories that started close together can pass each other on different onion skins such that in the 3D state space of the system they are close together but if we were to trace their trajectories back through time, we find they have been diverging continuously.

The geometrical visualization of a system's behaviour as a trajectory, tracing a path through a state space, whose axes define the key attributes of the system, makes the concept of an attractor, a restricted region of state space that the system trajectory is drawn to, easy to visualize. Indeed, the geometrical treatment of non-linear systems in general and complex systems in particular has been a powerful tool in advancing our understanding of their behaviour and it is the lens through which societal dynamics has been viewed in this paper. For a more rigorous mathematical treatment of these ideas see for example, Tabor (1989) or many other readily available books and papers.

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The science and politics of climate change

Brian Spies

Australian Academy of Technological Sciences and Engineering, NSW
Email: brian@spiesmail.com

Abstract

The scientific evidence of climate change has developed rapidly over the past 30 years, with an overwhelming array of scientific data supporting the view that human activity, in particular greenhouse gas emissions from burning fossil fuels, has a measurable and accelerating influence on Earth's climate. The scientific process underpinning climate science is no different to any other peer-reviewed field of science. Scientists are sceptical by training and continually challenge ideas, revise theories and subject their work to critical peer review, in a continual loop that drives scientific understanding. Despite what we hear in the popular press, there is very little disagreement among climate scientists on the broad trends in climate change and mankind's influence, or on what needs to be done about it. Why then do climate change deniers have such a strong voice in the media? This paper will attempt to unravel the science from the politics, describe typical emotional responses, and discuss the importance of, and barriers to, achieving an international agreement on reducing emissions.

Introduction

Why does the topic of climate change provoke such polarised and antagonistic responses in much of the population and across politics? Ross Garnaut in his 2008 review referred to climate change as a "diabolical problem", where doing nothing is not an option and yet policy responses must include most of the world's governments. Harvard economist Daniel Gilbert states "A psychologist could barely dream up a better scenario for paralysis than climate change" (Halstead, 2014). Mark Carney, Chair of the Bank of England, famously described climate change as "a tragedy of horizons, the longer you leave it, the more costly it will become". Nicholas Stern, Former Chief Economist of the World Bank, argues that climate change is the biggest example of market failure the world has ever seen.

In Australia, political response to climate policy has seen the overthrow of leaders of the two major political parties and change of government. The tortuous evolution of Australian climate policy since 1972 is summarised by the Parliamentary Library (Talberg et al., 2016) who comment, "Australia's commitment to climate action over the past three decades could be seen as inconsistent and lacking in direction."

This paper will first describe the process of science as a discipline, the current state of understanding of climate science and why the public at large, as well as politicians, are so divided in their beliefs. The paper then summarises the workings of the Intergovernmental Panel on Climate Change (IPCC), climate projections and recent climate data, implications of the 2015 Paris Climate Agreement and steps required to limit global warming to 2°C through rapid decarbonisation of the economy. As demonstrated in many overseas jurisdictions, visionary governments and reasoned public discourse can largely overcome vested interests to create business and employment opportunities to

transform the economy and improve health and social outcomes, but this goal appears elusive in Australia.

Is science a belief?

The oft-asked question "Do you believe in climate change?" reflects a fundamental misunderstanding of the scientific process. Religious dogma dominated belief systems until the 18th century, when the Enlightenment, or the Age of Reason, and the scientific method brought rigour and academic processes as the key source of authority and legitimacy. The Enlightenment built upon the scientific revolution sparked by the publication of Nicholas Copernicus' *De revolutionibus orbium coelestium* (On the Revolutions of the Heavenly Spheres) in 1543, followed by the seminal works of René Descartes, Galileo Galilei and Isaac Newton.

Karl Popper, one of the most influential philosophers of the 20th century, described criteria to distinguish scientific theories from metaphysical or mythological claim. Popper's techniques (Popper, 1959) are based on the methodology of falsification, whereby scientific theories are characterised by entailing predictions that future observations might reveal to be false. Einstein's general theory of relativity, for instance, predicted that light rays would be bent by gravity, and was later shown to account for discrepancies in observations of the transit of Mercury over the Sun that could not be explained by Newtonian physics. Thomas Kuhn (1962) challenged the prevailing view of incremental progress of science, and argued for an episodic process of revolutions in scientific theory as, for instance, Copernicus overturned the Ptolemaic model of Earth as the centre of the cosmos and Dalton's atomic theory explained the formation of chemical compounds, developments Kuhn referred to as "paradigm shifts".

The origins of climate science can be dated back to Joseph Fourier in the 1820s, who posited that the earth's atmosphere played a pivotal role in preventing the earth from freezing into a ball of ice. John Tyndall's laboratory experiments in 1861 demonstrated that gases such as methane and carbon dioxide absorbed infrared radiation, and could trap heat within the atmosphere. Svante Arrhenius, a Swedish chemist, provided the first numerical estimates of "climate sensitivity" — defined as the temperature change corresponding to a doubling of carbon dioxide in the atmosphere. He suggested a value around 4°C in 1896, which is within the range of current estimates. Weart (2008) gives an excellent overview of the early theoretical and experimental work that underpins climate science and more recent climate change research.

One of the aims of science is to develop models that account for as many observations as possible within a coherent framework. Climate models, first developed in the 1950s, have steadily improved as increased computational power has enabled more parameters to be included in models of increasing complexity and resolution. By the late 1990s climate predictions could be reliably matched with observed data, and the resulting improved understanding of uncertainties in data and models increased confidence in climate projections into the future under a range of scenarios.

There has been no "paradigm shift" in the understanding of climate science — instead, a continual, relentless and dedicated effort by thousands of scientists around the world to improve the certainty and accuracy of climate modelling, supported by the col-

lection of vast quantities of climatological data across the globe, the atmosphere and the oceans.

Climate science is like any other branch of experimental science — a process of painstaking and careful observation, the development of hypotheses and theories to explain the data, testing predictions from physical, chemical and numerical models, and the forging of scientific consensus through rigorous peer review and publication. Scientists are sceptical people by training, and are constantly trying to test and improve scientific understanding. The scientific process is designed, as far as is possible, to objectively understand how the world works, without the burden or constraint of ideology and dogma.

Asking "do you believe in climate change?" is akin to the questions "do you believe in gravity?" or "do you believe in cancer?" More logical questions would be "What causes climate to change, do humans play a role and can anything be done to mitigate those changes?" Extending the questions to "is the cost worth the effort?" and "who are the winners and losers?" extends the debate away from science into economics and sociology.

Belief systems

There is a disjunct between views of scientists and the general public, and between conservative and progressive sides of politics. In an American survey (Figure 1), around half of the public said that they believe that "human activity is a significant contributing factor in global warming" and they thought about half of scientists held the same views. In reality, around 97% of climate scientists have no doubt about anthropogenic climate change (Cook et al, 2013). The authors did note, however, a lower level of acceptance among scientists without expertise in climate science, particularly economic geologists.

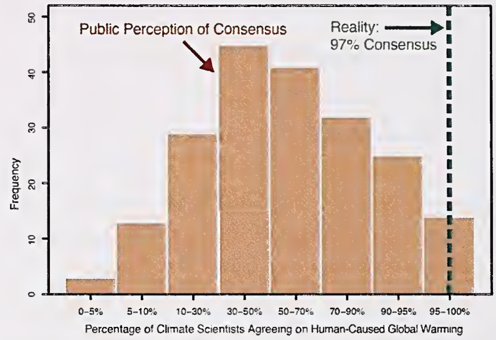

Figure 1: Public and scientific consensus on human induced climate change (data from Doran and Zimmerman, 2009, and Cook et al, 2013).

They go on to say, "The challenge appears to be how to effectively communicate to policy makers and to a public that continues to mistakenly perceive debate among scientists."

Politically, Democrats and Republicans in the USA have grown further apart in their attitudes and beliefs about climate change over the past few decades, although there was bipartisan support for climate action in the 1980s (Cook, 2016). The difference in opinion is strongly related to belief systems — conservatives (right-wing) tend to favour small government and resist actions to limit individual freedom and impose regulations. Liberals (left-wing) support government regulation to achieve social, environmental and economic outcomes that benefit society as a whole. The partisan influence on climate change views, referred to as the "liberal consensus gap" can be up to 40 percent. If a person doesn't want to believe that humans are causing climate change, they will ignore the hundreds of studies that support that conclusion, but latch onto the one study they can find that casts doubt on this view (Macdonald 2017). Among Republicans,

higher levels of education correlate with higher levels of rejection of scientific consensus (Oreskes, 2017).

There is deep-rooted belief in US culture that "government that governs least governs best", and that accepting climate change science will inevitably lead to an expansion of government and constriction of personal freedoms (Oreskes and Conway, 2010). Those who don't want government action, for either economic or philosophical reasons, are likely to reject the science and attack the scientists.

Differentials between the left and right sides of politics are also seen in Australia. Taylor (2015) explores the factors involved in the evolution of Australia's political attitudes, including carbon-intensive industries combining their lobbying effort, sections of the media supporting a new narrative describing the essential role of coal and an open scepticism of the science, regulatory capture and cultural change, primarily the rise in neoliberal economics.

Media, too, play an important role in influencing public opinion; with some media outlets promoting clearly biased views on climate science, as well as misinformation, to the public. Dissent (whether real or imagined) sells newspapers.

Ideology against action on climate change has evolved in what the *New York Times* refers to as the Culture Wars. The attack on science is relentless and dangerous. Conservative commentators, fossil-fuel companies and well-funded lobby groups have led the attack to subvert the public understanding of the science. The Heartland Institute, for example, spent $100,000 in spreading the message in K-12 schools that "the topic of climate change is controversial and uncertain — two key points that are effective at dissuading teachers from teaching science." In Australia, climate change deniers have been appointed to chair government enquiries into energy policy, and at least one Government Minister consulted Wikipedia for a view on climate change rather than experts in CSIRO and the Bureau of Meteorology.

Denial and confusionists

Why do people respond so differently to the science and implications of climate change? Part of the answer lies in the worldview and ideological preferences of the individual, as discussed above, but the roots go far deeper.

Not surprisingly, psychologists have taken a keen interest in the human and behavioural aspects of the challenge of climate change. One segment of the population readily accepts the science and is ready to address the problem. For others, the threat posed by climate change elicits a wide range of feelings, which may include sadness, distress, shame, guilt, despair, loss and grief (The Australian Psychological Society, APS, 2010, 2014), Doherty and Clayton (2011), Reser, et al. (2011) and Härtel and Pearman (2010).

People may react to these feelings by:

- Minimising or denying that there is a problem,
- Avoiding thinking about the problem,
- Being sceptical about the problem, or
- Become desensitised to information.

If people feel they can't change a situation, they may become:

- Resigned ("if it happens, it happens"),
- Cynical ("there's no way we can change things"),
- Dependent on others (eg government) to act, or
- Become "fed up" with the topic.

Given the broad range of personality types, worldviews and ideologies, is it any wonder that climate change policy has become such a divisive issue? (Jones, B, 2010, Pearman and Härtel, 2010, Garnaut, 2011).

The IPCC — The best summary of climate science

The Intergovernmental Panel on Climate Change (IPCC) is a scientific and intergovernmental body, set up in 1988 under the auspices of the United Nations, with the task of providing the world's governments with an objective, scientific view of climate change and its political and economic impacts.

IPCC reports cover the scientific, technical and socio-economic information relevant to understanding of climate change, its potential impacts and options for adaptation and mitigation. The IPCC does not carry out its own original research, but bases its reports on the vast array of published literature.

Thousands of scientists and other experts contribute to writing and reviewing reports, which are then reviewed by governments. IPCC reports contain a "Summary for Policymakers", which is subject to line-by-line approval by delegates from all participating governments. Typically, this involves the governments of more than 120 countries. The IPCC provides an internationally accepted authority on climate change, producing reports that have the agreement of leading climate scientists and the consensus of participating governments.

The IPCC's first assessment report was completed in the 1990s, and the most recent (5th) report in 2014. The IPCC also issues special reports on topics such as emission scenarios, renewable energy, extreme events, mitigation and adaptation. With each edition, as more data are collected and models improve, the evidence for anthropogenic global warming becomes more compelling. The 2007 report concludes "Global warming *very likely* shows a significant anthropogenic contribution over the past 50 years" and the 2014 report "It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century" (my emphasis).

Since over 2,000 peer-reviewed papers on climate science are published every year, no one person is able to absorb and understand the vast array of information available. The IPCC is arguably the most robust system in the world for summarising a science — yet all too often, "climate-deniers" choose one or two papers, carefully cherry-picking graphs and statements to support their views.

Globally, leading scientific organisations and academies have issued position statements supporting the consensus on human-induced climate change, e.g. https://climate.nasa.gov/scientific-consensus/ .

In Australia, regular summaries of climate science, observations and projections are published by the country's premier science organisations. The CSIRO and Bureau of Meteorology publish *State of the Climate Reports* every two years, most recently in 2016. The Australian Academy of Science publishes *The Science of Climate Change — Questions and Answers* (the 2015 edition has 370 references!). The reader is referred to these reports as well as the IPPC web site, NOAA (climate.gov) and NASA (climate.nasa.gov) for a plethora of expert coverage of climate science.[1]

[1] Note that in January 2017, the Trump administration began restricting public access to climate data, e.g. mandating that scientific data published by the EPA (Environmental Protection Agency) undergo review

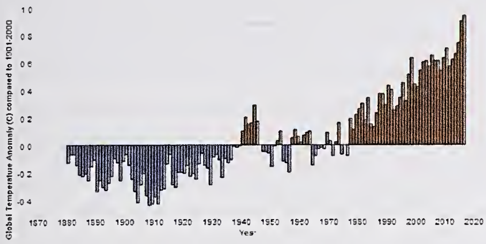

Figure 2: Global temperature anomalies from 1880 to the present compared to the long-term average (1901–2000). Blended land and ocean data (NOAA https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature).

Weather and climate

Weather describes short-term changes in the atmosphere over time periods of minutes to months, whereas climate describes how the atmosphere behaves over longer periods of seasons to millennia.

What's happening to the Earth's climate?

This paper cannot hope to comprehensively cover climate science — the reader is referred to the sources listed above. The key evidence for climate change is compelling:

The Earth is warming

Figure 2 shows annual global land and ocean temperatures since 1870. Yearly fluctuations are caused by El Niño and La Niña and other weather events, volcanic eruption, etc.

The long-term trend is clear (though climate change deniers often select particular years or geographic locations to demonstrate that the world is cooling.) Since 1976, every year has had an average global temperature warmer than the long-term average. Most of the warming has occurred in the past 35 years, with 15 of the 16 warmest years on record occurring since 2001. The three most recent years, 2014, 2015 and 2016 were the hottest years on record (World Meteorological Organisation).

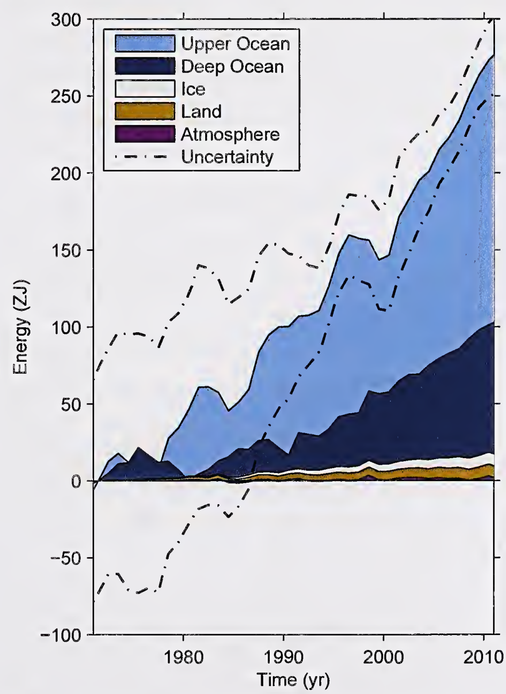

Figure 3: Changes in ocean heat content since 1970. Most of the excess heat from global warming is stored in the ocean. The heat capacity of the top metre of the ocean is the same as the entire atmosphere (IPCC 5th Assessment Report).

by political appointees before publication. Activists in the USA and Canada immediately began an archiving program in a "race" to save U.S. government's climate data Science, Jan 25 2017 http://www.sciencemag.org/news/2017/01/trump-officials-suspend-plan-delete-epa-climate-web-page; *New York Times*, Jan 25 2017 https://www.nytimes.com/2017/01/25/us/politics/some-agencies-told-to-halt-communications-as-trump-administration-moves-in.html. Australia's Chief Scientist observed "Science is literally under attack" http://www.smh.com.au/technology/sci-tech/donald-trump-like-stalin-says-chief-scientist-alan-finkel-as-science--literally-under-attack-20170206-gu6f5w.html.

Where does the heat go?

Since 1955, over 90% of the excess heat trapped by greenhouse gases has been stored in the oceans (Figure 3). The top 700 m of ocean warmed 0.16 degrees C since 1969. The remainder of this energy goes into melting sea ice, ice caps and glaciers, and warming the continents' land mass.

Global sea levels rose about 17 cm in the last century, and the rate is accelerating. Half of the sea level rise is caused by thermal expansion of the oceans, and half by melting ice caps and glaciers currently grounded on land.

Only a small fraction of the thermal energy goes into warming the atmosphere. Humans, living at the interface of the land, ocean and atmosphere, only feel a sliver of the true warming cost of fossil fuel emissions. Ocean Scientists for Informed Policy (www.oceanscientists.org) is a good resource for ocean science.

Further evidence

Other observations, summarised from NASA's Global Climate Change information service, include

- Shrinking ice sheets—The Greenland and Antarctic ice sheets have decreased in mass. Greenland lost 150 to 250 cubic km of ice per year between 2002 and 2006, while Antarctica lost about 152 cubic km of ice between 2002 and 2005.
- Declining Arctic sea ice—Both the extent and thickness of Arctic sea ice have declined rapidly over the last several decades. If current trends continue, the summer Arctic could be ice-free by mid- century, for the first time in 125,000 years.
- Glacial retreat—Glaciers are retreating almost everywhere around the world, including in the Alps, Himalayas, Andes, Rockies, Alaska and Africa.
- Extreme events—The magnitudes of extreme events such as hurricanes, temperature extremes and intense rainfall event are increasing.
- Ocean acidification—Since the beginning of the Industrial Revolution, the oceans have absorbed one-third of the carbon dioxide we have produced. This has caused an increase of 30% in surface ocean acidity. The last time the oceans were this acidic was 53 million years ago.
- Decreased snow cover—Satellite observations reveal that the amount of spring snow cover has decreased over the past five decades and that the snow is melting earlier.

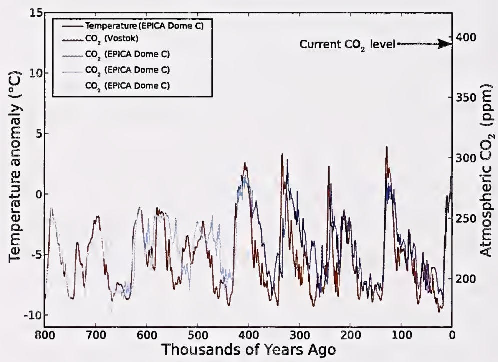

Figure 4: Temperature and CO_2 levels for the last 800,000 years, based on data from Antarctic and Greenland ice cores. Current CO_2 levels are over 400 ppm, and rising at an accelerating rate of 3.3 ppm/year (IPCC).

Long-term records

Data from isotopic analysis of deep ice cores show that CO_2 levels are now higher than at any time over the past 800,000 years (Figure 4).

During ice ages, atmospheric CO_2 levels were around 200 ppm, and during the

warmer interglacial periods, they hovered around 280 ppm.

Most of the past climate changes are attributed to very small variations in Earth's orbit that change the amount of solar energy our planet receives. In 2013, CO_2 levels surpassed 400 ppm for the first time in recorded history.

Climate modelling

Massive computer models, known as General Circulation Models or GCMs representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools available for simulating the response of the global climate system to increasing greenhouse gas concentrations. Dozens of research agencies around the world develop, improve and compare model outputs in each IPCC round; differences in model runs are used to assess uncertainty in climate projections.

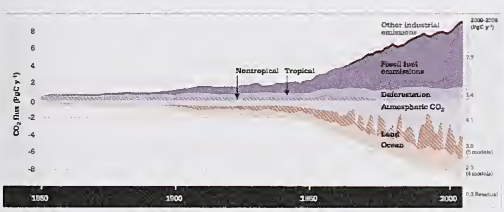

Figure 5: Global CO_2 budget, 1850 to 2008. Note the rapid increase of CO_2 emissions since 1950, most of which is then stored in the atmosphere and oceans (Raupach and Canadell, 2010).

Using climate models, it is possible to separate the effects of natural and human-induced influences on climate. Models successfully reproduce the observed warming over the last 150 years, when both natural and human influences are included, but not when natural influences act alone. Modelling clearly shows that most of the observed recent global warming results from human activities rather than natural influences on climate.

Greenhouse gas trajectories

Global greenhouse gas emissions have risen rapidly since the 1950s, primarily from fossil fuels, industry and land use change. They end up in the atmosphere and carbon sinks on land and in the ocean (Figure 5). If it were not for the substantial uptake of carbon by the terrestrial biosphere, the accumulation of CO_2 in the atmosphere would have been much more rapid.

With continued strong growth in CO_2 emissions under the "business as usual" scenario, much more warming is expected. Figure 6 shows two future scenarios for fossil fuel emissions — a high-emission pathway if the world continues to burn fossil fuels at present rates (red lines) and a low-emission pathway with deep, immediate deep emission cuts (blue).

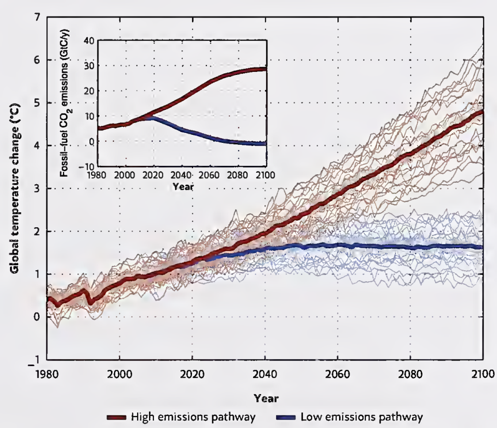

Figure 6: Projections of future changes in climate under low- and high-emission pathways. The inset shows the two scenarios for CO_2 pathways, and the main graph the resulting temperature changes. Individual model runs are shown as light lines, and the average as sold lines (graphic from Australian Academy of Science, 2015).

Half the CO_2 emitted stays in the atmosphere and lasts 50–100 years. Thus, even if emissions reduce markedly, warming due to the greenhouse effect is largely unchanged. According to a recent National Academy of Sciences report (Solomon et al., 2009), "the climate change that takes place due to increases in carbon dioxide concentration is largely irreversible for 1,000 years after emissions stop".

Rapid decarbonisation of the economy can slow global warming, but will not reverse it! Warming of 1 to 1.5°C is already locked into the system. Society can potentially adapt to a 2°C-warmer world, but 4 to 5°C degrees of warming would be catastrophic, with widespread famine, flooding, heat waves and much of the world's populations displaced (World Bank, 2014).

The Paris Climate Change Agreement

COP-21 (the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change), held in Paris in December 2015, was the most decisive of a series of international meetings attempting to reach agreement on policies to limit the impact of human activities on climate change. The journey has been slow and disjointed as developed countries most able to reduce emissions jostled with developing countries with growing populations demanding financial assistance before taking action.

The breakthrough in Paris was the establishment of a clear goal for containing global warming — reaffirming the intent to limit global temperature increase to below 2°C while urging efforts to limit the increase to 1.5°C, and the establishment of binding commitments for countries to reduce greenhouse gas emissions (which include CO_2, methane and nitrous oxide). Australia, for its part, agreed to implement an economy-wide target to reduce greenhouse gas emissions by 26% to 28% below 2005 levels by 2030. Countries also committed to submit new contribution targets every five years, with the clear expectation that they will "represent a progression" beyond previous ones.

The 2°C goal is feasible only with immediate and strong international action, especially by the major emitting countries. Current global commitments are insufficient. Australia's current reduction target for 2030 falls far short of that required to meet the 2°C goal — a "fair share" would be closer to 40% to 60% below 2005 levels by 2030 rather than 26% to 28%.[2]

Decarbonising the economy

The 2°C target will require most countries to cut their net greenhouse gas emissions to zero in the second half of the century.

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[2] The Climate Change Authority (2014) concludes that Australia's reduction targets are inconsistent with a "fair" contribution to the long-term global goal, because 1) they won't keep pace with actions in many other countries, and 2) stronger targets are easier to achieve than previously thought. They suggest:

- 2020 target 15% below 2005 levels — carry-over from pre-Kyoto commitment gives 19% below 2000, and
- 2030 target of 40–60% below 2005 levels.

The corresponding national carbon budget would be:

- 4,193 Mt CO_2e 2013–2020 (580 Mt CO_2e in 2013 ramping down to 480 Mt CO_2e in 2020),
- 10,100 MtCO_2e 2013–2050 (ramping down from 480 Mt CO_2e in 2030 to ~270 Mt CO_2e in 2050),
- and zero net emissions by 2045.

Australia is on track to achieve its stated 2030 target, with projections for annual emissions of around 600 Mt CO_2e in 2030 (Dept Environment and Energy 2016b), but has no strategy to achieve the longer-term targets needed to meet the global goal of reducing warming to 2°C below pre-industrial levels.

Massive transformation of the world's energy mix will be required — more than 80% of the world's coal, 50% of gas and 30% of oil reserves are "unburnable" and must remain in the ground (Jakob & Hilaire, 2015; McGlade & Ekin, 2015).

Globally, US$348 billion was invested in clean energy in 2015, mostly in China, with a steadily declining investment in fossil fuels as industry moves to a more sustainable footing. The International Energy Agency predicts "Driven by continued policy support, renewables will account for half of additional global generation, overtaking coal by 2030 to become the largest power source." The cost of solar generation, in particular, is falling rapidly, and the amortised cost per GWh is now comparable with fossil fuel plants in many parts of the world, and battery storage costs are also decreasing at an astonishing rate.

Around two-thirds of Australia's emissions are from the energy sector, followed by agriculture and other forms of land use (Dept Environment and Energy, 2016a). The Climate Change Authority (2016a,b) has developed a toolkit to align Australia's climate goals and policies, including a detailed study for Australia's electricity supply sector. Detailed studies have also been produced by the CSIRO, ANU, Grattan Institute and The Climate Institute, among others.

The renewable energy target (RET), not without controversy, is one important mechanism for Australia's transition to a low-carbon economy. The Federal Government's renewable energy target for 2020 is ~23% (23,000 GWh), with no plans for increases beyond that date. The States and Territories, motivated by widespread public support, have led the charge on aggressive (and possibly aspirational) growth in renewable energy: 50% by 2030 for Queensland, 50% by 2025 for South Australia, and 40%/50% by 2025/2030 for Victoria. The ACT plans to be 100% renewable energy powered by 2020, and NSW and SA aim for zero net emissions by 2050. Australia's Chief Scientist, Alan Finkel, is chairing a review commissioned by the COAG Energy Council to recommend how to integrate the increasing proportion of renewable energy and maintain security and reliability of the National Electricity Market.

Regulation or market-based?

With any transformation, there will be winners and losers. Incumbents fiercely protecting the status quo, while entrepreneurs and nimble companies pursuing opportunities in transforming the economy. Australia, unlike Europe, has experienced much political turmoil over policy, most recently relating to carbon pricing and the renewable energy target (RET).

Policy levers can be broadly grouped into two categories:

- Market-based mechanisms with fixed or floating price, such as cap-and-trade, carbon tax, baseline intensity and emissions intensity schemes, and
- Regulation or direct action (incentives and penalties) such as mandated closures of high-emission electricity generators, emissions reduction funding (with or without safeguard mechanisms), RETs and energy efficiency mandates.

Economists broadly favour emissions trading (cap-and-trade) as being the lowest-cost approach, as industry has shown itself to be particularly adept at rapid innovation in technologies to drive down costs and exploit opportunities when given appropriate incentives to do so. In practice, a judicious combination of both approaches is optimal.

Opportunities and transformation

To a large extent, business understands the risks and opportunities posed by climate change, with initiatives such as the Carbon Disclosure Project (www.cdp.net/en) encouraging companies to publish their greenhouse gas emissions. The Financial Services Council and the Business Council of Australia stress the importance of assessing climate risk on business operations. AGL, Australia's largest greenhouse gas emitter, will close all its coal-fired power stations by 2050 and has launched the *Powering Australian Renewables Fund* to spur investment and development to support Australia's transition to a low-carbon economy. Royal Dutch Shell, among others, is pursuing opportunities in Australia to support what they term "the unstoppable transition to a cleaner economy." President Obama regards the trend towards clean energy as "irreversible" (Obama, 2017).

Paul Fisher, Chair, G20 Financial Stability Board, speaking in Sydney on 20 Oct 2016 said, "I saw climate change go from being an issue that was sociopolitical, ethical, moral, if you like, to being front and centre as a hard commercial issue. We need to sweep the politics to one side and say this is just a commercial business risk, like any other, that we need to take into account."

A myriad of sociological, economic and political barriers exist with respect to any change, particularly one so disruptive and revolutionary as needed to address climate change. Individuals have strong behavioural practices and belief structures but so too do institutions and companies, which are inherently conservative, and often governed to protect vested interests, and sometimes aiming to exploit the system through rent seeking.

Meeting Australia's ambitious emission reduction targets will be demanding of successive Australian governments. There is an urgent need for visionary leadership, both at the corporate and Governmental level. A de-carbonised world will be different from today and the transition presents large challenges and commercial opportunities.

In summing up, my conclusions cannot be expressed better than by Nicholas Stern, the author of the influential 2009 Stern Review on the economics of climate change.

> "We have the knowledge to act now, and that the outcome will be a cleaner, safer, more biodiverse and more prosperous world. The alternative — business as usual — will cost more, undermine growth and lead to immense conflict, dislocation and loss of life. Delay will greatly exacerbate the burden on society. The argument about whether we should act strongly and urgently is over — or should be."

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A systems approach to public health

Stephen J. Simpson

Director, Charles Perkins Centre, University of Sydney, Sydney, Australia
Email: stephen.simpson@sydney.edu.au

Abstract

The modern burden of chronic diseases such as obesity, diabetes, cardiovascular disease and related conditions is the result of a complex web of interacting factors, with the individual sitting at the nexus of a network of biological, social, societal and environmental forces that together impact their risk of disease. Our biological predispositions to chronic diseases have origins deep in evolutionary history. There is no simple solution or medical intervention that will solve these problems. The Charles Perkins Centre at the University of Sydney was designed as a new model for addressing the burden of chronic disease based on principles from evolutionary biology and ecology. It brings together multidisciplinary teams spanning philosophers to clinicians in a complex adaptive research ecosystem, from which are emerging unexpected linkages and new solutions.

Introduction

In Australia 63% of adults and 25% of children are now classified as overweight or obese (ABS, 2013). These numbers show no real sign of abating and there are major impacts on health, particularly through associated comorbidities (O'Rahilly, 2016). Overweight and obesity have not yielded to public health campaigns urging us to eat less and move more. If the rise in chronic disease burden was simply the result of individuals not taking personal responsibility for their lifestyles, then it would represent a failure of willpower of monumental proportions. Rather, the explanation is more complex. In essence, we have designed our world in every respect to make it difficult to live a healthy lifestyle.

Like all animals, humans have evolved to minimize energy expenditure and maximize accessibility to safe and palatable food. These are powerfully adaptive traits, but because of our most notable adaptation — the human brain — we have designed a world in which we have achieved our ancestral hearts' desires. We have bred our food plants and animals and designed our food production and supply systems to maximize the qualities missing in our ancestral environments — energy dense, fat and sugar-rich foods; our towns, homes and workplaces are designed to allow minimal energy expenditure; our economic systems are designed to value wealth over health. In the Darwinian market place of the modern economy, companies that sell what we want prosper, even if that means selling us foods that degrade health. Political solutions are not easy — prevention is better than cure, yet makes little profit and wins few votes in the short term. As a consequence, although in the developed world we benefit from the longest average lifespans in human history and enjoy unprecedented food security and wealth (albeit increasingly unequally distributed), we are nonetheless suffering an epidemic of non-communicable diseases.

Building a complex adaptive system to tackle a complex societal problem

Complex adaptive systems have been the greatest solvers of hyper-complex problems in the history of the known universe. Evolution by natural selection has given rise to the wonders and diversity of life-forms that populate our planet; modifiable interactions between nerve cells give rise to the complex computing powers of brains and to the emergence of consciousness, and interactions between genes, signalling molecules and cells in the embryo ultimately give rise to the fully formed organism through the processes of development. How better, then, to tackle the complex issues of chronic disease than by building a complex adaptive research and education ecosystem?

Universities are pre-adapted to undertake such a task. They are populated by a continuing stream of young clever people full of energy, at the peak of their creativity and ready to learn. Universities possess expertise across a diversity of disciplines, giving the potential for both depth and breadth. But this potential has been hard to realise because, traditionally, universities have been built as a collection of separate disciplinary entities — Faculties, School and Departments. At the Charles Perkins Centre we have set out to design a system that brings disciplines together and augments rather than dilutes specialist expertise.

The Charles Perkins Centre (CPC) was set up to bring the University together across its disciplines and locations by establishing new collaborative, multi-disciplinary research and education that has impact on peoples' lives. The centre's namesake is Dr Charles Perkins, an alumnus of the University of Sydney and the first Aboriginal man to gain a University degree. Charles exemplified many of the characteristics we wished for the Centre: he worked across sectors of society, he challenged prevailing ways of thinking, and he made an impact (Read, 2001).

The Charles Perkins Centre research and education hub

To serve both as a physical manifestation of the ethos of the centre and act as its headquarters, a new building was designed, built and populated on central campus adjacent to the Royal Prince Alfred Hospital — the CPC research and education hub. The $385 million building was completed ahead of schedule and under budget and was formally opened in June 2014. The hub comprises nearly 50,000 m^2 of wet laboratories, dry laboratory areas, advanced teaching spaces, high-end core facilities and a pathology museum. It has its own clinic, The Charles Perkins Centre Royal Prince Alfred Clinic, run under the clinical governance of the hospital to the CPC academic strategy, admitting patients, delivering new forms of care and research, and linking the patients back into the basic research within the building. The building is home to more than 850 researchers, educators and practitioners, spanning engineers to philosophers, economists to clinicians, metabolic scientists, computer scientists and mathematicians, public health and policy researchers, and many more.

The building is not the entirety of the centre, however. Across all locations there is now a network of more than 1,200 CPC members engaged in the research and educational activities of the centre (membership is defined by initiating or joining such an activity). Regional hubs have been established at Broken Hill, Nepean and Westmead, and CPC members are found across all faculties, and beyond the University.

The academic strategy of the Charles Perkins Centre as a complex adaptive system

The main novelty of the CPC lies in its academic strategy, which was explicitly designed as a complex adaptive system. In any such system there are interacting entities or agents, interactions among which lead to higher order 'emergent' phenomena. Importantly, such self-organised emergent outcomes cannot simply be predicted from the individual activities of each of the interacting agents. Similarly, the agents themselves cannot make those predictions, or even necessarily understand the entirety of what they are involved in.

The core principles in setting up the Centre as a complex adaptive system were to:

- Make it attractive and easy for individual researchers to engage, and make it worthwhile for their home Faculties to let them;
- Set the rules of engagement to value ambition, collaboration, sharing and partnership;
- Make it easy to find compatible expertise, thereby keeping disciplinary depth and gaining breadth;
- Set a single overarching mission, but not prefigure routes to that end, constrain what is done based on presumptions of what is relevant, or insist on everything being directly translatable (useful);
- Construct the system around specific projects, which provide the basic nodes from which to build the collaborative network. Such 'project nodes' will yield new knowledge, but also inevitably interconnect to share knowledge and insights and ultimately yield larger outcomes;
- Allow projects nodes and collaborations to seek resources, grow, morph and die organically, such that the CPC system as a whole evolves;
- Capture and communicate these outcomes for public good;
- Foster entrepreneurship and commercialisation.

Any complex system needs boundary conditions and a framework. The Charles Perkins Centre academic strategy is not structured around diseases — for example by having domains of activity for obesity, diabetes or cardiovascular disease, as would perhaps be more conventional. There are, instead, four domains that define disciplinary areas. These are: population health; the biology of disease processes; society and environment, and a domain called 'solutions', to which all pathways directly or indirectly lead, providing the translational flow for the centre. There are in addition six cross-cutting themes that intersect all four domains. These are: nutrition; physical activity, exercise and energy expenditure; sleep; Aboriginal and Torres Strait Islander health; ethics, politics, and governance of chronic disease; and complex systems and modelling. The last of these themes involves mathematicians and computer scientists spanning areas of activity from metabolic networks, to the communities of micro-organisms that inhabit the gut and impact health, to human social networks.

These four domains and six themes form the basic framework for the strategy. The framework has been populated by newly established project nodes, which now total 67 in number. These have each been established around particular multidisciplinary research projects under the direction of the CPC Executive Committee and engage CPC members in a dynamic and exponentially growing collaborative network (Table 1).

Since inception of the academic strategy in June 2012, this network has not only grown in number of members and nodes, but it has also yielded an exponential increase in productivity and impact. One measure of this can be seen in numbers of co-authored, peer-reviewed publications among members (Figure 1). Other measures that have shown strong growth include public engagement (as indicated by media impact of the work of the centre and events held under the auspices of CPC), industry and government engagement, competitive grant funding (e.g. CPC members have secured more than 40% of the University of Sydney's income from the National Health and Medical Research Council for the past two years), changes to models of care in clinical practice, contributions to national and global policy debates and health reports, and philanthropic support (which now stands at $92 million). There has also been growing interest in emulating the CPC model at other institutions in Australia and abroad.

Emphasising common causes rather than disease-specific processes

The major chronic diseases share common underpinnings both at the mechanistic level and in their social and environmental determinants. It is through understanding these commonalities that the greatest dividends will arise for both prevention and cure. This is nowhere better demonstrated than in the case of the diseases of ageing.

The greatest risk factor for all chronic diseases is increasing age, with commensurate impacts on the costs of healthcare (de Cabo and Le Couteur, 2015). Rather than taking the traditional view, which is to research each disease condition separately and to seek specific medical interventions, our aim is to understand the basic processes of ageing biology and to seek common features that underpin all metabolically related diseases. The logic is that by understanding those common processes we can better mitigate multiple conditions, for example through diet, exercise, changes in sleep regime, and use of better targeted pharmacological interventions, and do so in a more targeted way that takes account of the particular needs and circumstances of different populations.

This is just one of the philosophies that the CPC has started to deploy in its research, integrating new advances in nutritional biology (Raubenheimer and Simpson, 2016), work in animal models (Solon-Biet et al., 2014), clinical trials and human cohorts (Le Couteur et al., 2016), and emphasizing metabolic systems as the nexus between genes and environment (Humphrey et al., 2015). Such an approach has provided the basis for a new program in precision medicine, which will provide a focus for the work of the CPC over coming years.

Table 1. List of CPC project nodes as at December 2016

Cardiovascular clinical project node	Human-animal interactions
Dog ownership and human health	Life Lab
Cardiac translational imaging	Lifestyle management clinical project node
Community Academic Partnerships (CAP) in health, wellbeing, and health workforce development: building an evidence base regarding impact	Obesity services in the Nepean region
BABY1000	Nutrition, ageing and health
Businesses, markets and the social context of health	PLANET Sydney network
CPCNet—Measuring the value add of CPC collaborative networks	Nutrition, human health and natural resources
Chronic disease management clinical project node	Preventative cardiology
Climate adaptation and health	One welfare
Child and adolescent mental health	Living healthier lives under the Australian sun
Brain and body	Population analysis of human diet and nutrition
Aboriginal nutrition, physical activity and wellbeing	Science of learning science
Bias in research	Schizophrenia: cardiometabolic and other medical comorbidity
Developmental Origin of Health and Disease (DOHaD)	Politics of obesity
Building system wide capacity for complex and big data analysis and storage in T2D	Remote/Indigenous communities—responding to community led innovation.
Gut microbiome	Positive computing in health systems
Endocrinology and diabetes clinical project node	Regional governance and leadership in addressing rural and remote health outcomes: A far west NSW initiative
Health and creativity	Smart food production systems
Health literacy chronic disease network	Women's health clinical project node
E-health in gaming and avatars	Translational gerontology
Health informatics and health analytics	Wireless wellbeing and personalised health
Healthy Food Systems: Nutrition diversity safety (formerly Global Food and Nutrition Security)	Work and health
Early prevention of obesity in childhood	Virtual reality
Health humanities	Twin project node
Health and economics: cross-portfolio impacts of health on individuals and families	Tissue Engineering and Regenerative Medicine (TERM)
Evidence synthesis	Theory and method in biosciences
Fibrosis and wound healing	Healthier workplaces
Implementation science	Food governance
Integrative Systems Lab (ISL)	Nutrition and cardiovascular health
Economics of human development	Writer in Residence
Human food chain	Oral and systemic health
Integrated care clinical project node	Immune therapies
Incidental physical activity and sedentary behaviour	Developing cell-based therapies for Type 1 diabetes
	Nutritional Immunometabolism

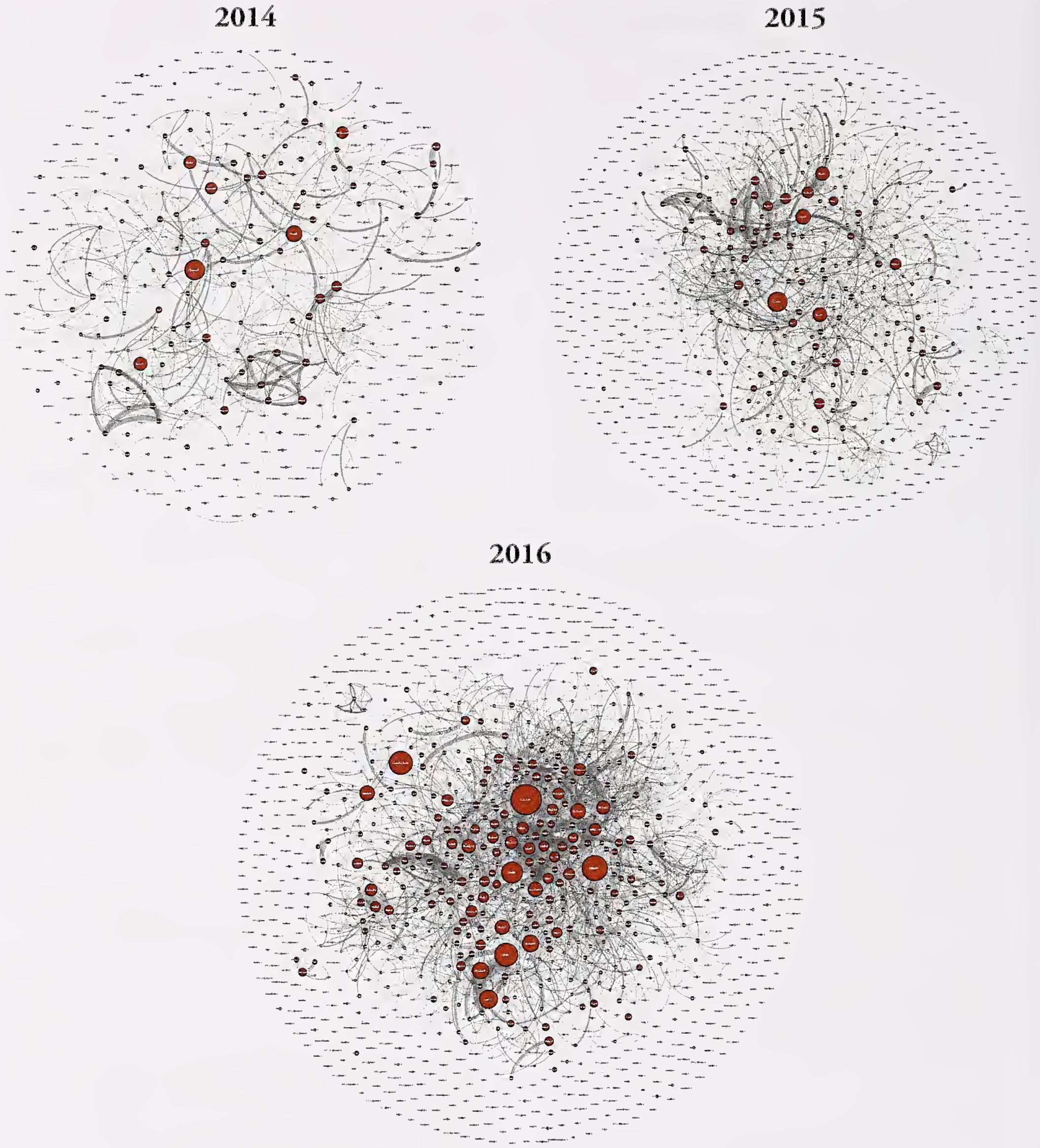

Figure 1. The publication 'connectome' of CPC members for 2014 (18 months after inauguration of the CPC strategy in June 2012), 2015 and 2016. Individual members are shown as red dots, the diameters of which reflect numbers of publications per member and the connecting lines between dots indicate co-authored publications in peer-reviewed journals. Note both the growth in number of members (ca. 500, 1000 and 1200 over successive years, from zero in June 2012) and the number of publications, but more than this, the growth in connectivity of the network, indicating establishment of new, productive collaborations among members, many of whom joined the CPC with no previous history of collaboration with other members.

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Water reform in the Murray–Darling Basin: a challenge in complexity in balancing social, economic and environmental perspectives

John Williams FTSE

Adjunct Professor, Crawford School of Public Policy, The Australian National University, Canberra, Australia

Adjunct Professor, Institute for Land, Water and Society, Charles Sturt University, Albury, Australia

Email: jwil3940@bigpond.net.au

Abstract

The Murray–Darling Basin is a very good example of a complex system. It is a complex system of environmental function in which snow melt and winter rain feed the south, while subtropical summer-dominant rainfall feeds the northern rivers. It is a complex system of re-engineering and readjustment of the natural and built infrastructure. It is also a complex system of human endeavour facilitating community adjustment and development, strongly driven by extremely high climatic variability and thus agricultural productivity, which is exposed to highly variable prices and demand for its produce. Then across the top of all this complexity is climate change, which is expected to impact further on increased climate variability. Thrust upon these complex interacting, biophysical, economic and social systems has been public policy in water reform to address the large over-extraction of water for agriculture from the rivers and groundwater aquifers of the Basin. Amidst all this complexity, public policy sought to return stressed rivers and groundwater systems to healthy conditions where floodplains, wetlands and riverine ecosystems regain a significant part of their ecological and hydrological function. Over $11 billion will be spent on the Basin Plan—a complex system in public policy and we are only in the middle of it. Despite this huge expenditure, the policy choices and processes are yet to show evidence that public benefit in a healthy river will be achieved.

Background

The problems confronting the Murray–Darling Basin (MDB) today come from an unfortunate collision of biophysical and economic reality, cultural values and public policy (Williams and Goss 2002; Williams 2011). The clashes and tensions between values, choice of public policies and knowledge have created land and water use patterns that are not well matched to the biophysical constraints of an ancient, flat, salty continent set in a dry, highly variable climate zone. Agriculture and associated development in the Basin have contributed to economic growth and population wellbeing equal to any in the modern world—but this economic growth has been achieved by exploiting the region's natural resources beyond their rates of replenishment. The result has been altered river flow regimes, rising salinity and acidity, loss of soil structure, increased loads of nutrients and sediments to rivers, and large-scale degradation of the rangelands. Measured by the invasion of environmental weeds and feral animals, the loss of flora and fauna species, and the breakdown of ecosystems, the environmental impacts are stark. The costs to the environment of the agricultural production systems are beyond dispute.

This collision of biophysical, economic, social and public decision-making systems can be seen as a clear case of the interactions and connections between at least four complex systems. Such level of complexity inherent in seeking to achieve water reform in the MDB has all the features of a well-known case of a "wicked" problem. It is not surprising, therefore, that it has continued to be a major issue in Australian public policy for over 100 years.

Because the MDB is a good example of a complex system, there is much we do not understand. What we do understand is often in isolated fragments. Some parts of the MDB complexity are discussed below, which will help to explain why there is such difficulty in bringing together a water reform agenda that will deliver healthy working rivers and groundwater systems. These are fundamental to sustainable irrigated agriculture and the diversity of other industries such as tourism, forestry and fishing, and in addition to conservation of the rich and diverse biodiversity of riverine wetlands and floodplain landscapes, which are part of our national and international heritage.

The major issue is how to bring the productivity, the economic resilience and the social wellbeing into play within the boundaries of a safe operating space for the biophysical and ecological functionality of the MDB.

The case for water reform in the Murray–Darling Basin

The story of water reform in the Basin is a long one (Connell 2007; Cummins and Watson 2012; Hart 2015a, b). I will focus on the recent period commencing with the MDB reform agenda of the 1990s, when there were repeated events and increasing concerns (Mackay and Eastburn 1990) of declining river condition as reflected in rising salinity; algal blooms; loss of native crustaceans, fish and aquatic vegetation; large areas of stressed and dying river red gum forests; and a general decline in the ecological condition of the Lower Lakes and the Coorong.

Whilst the documentation and assembly of evidence was fragmentary, over this period an audit of water use and environmental status was conducted and published in 1995 (MDB Ministerial Council 1995). The audit recommended a cap be placed on the extraction of water from the Basin river systems, but it did not include groundwater. It demonstrated that the river systems were seriously stressed, largely due to excessive extraction of water for irrigation which had radically changed the hydrology of the Basin to such an extent that drought-like flows were being experienced in 61% of years. The MDB Ministerial Council (1995) report stated that the drought which would have occurred in "one in twenty years under natural conditions, is now happening in six out of ten years."

This audit and the subsequent implementation of the cap ushered in the beginning of the most recent era of water reform in the Basin. Subsequently, increased investment in monitoring resulted in the development of a comprehensive suite of measures to characterise the ecological river conditions across all the rivers of the Basin.

In 2008 this culminated in the publication of the Sustainable Rivers Audit (SRA), which showed (as in Table 1 below) that the health of the river systems was not good and that most of the river systems in the Basin were in poor or very poor condition. This was further confirmed by the subsequent SRA in 2012.

However, the SRA program has now been abandoned. While there are still State and Commonwealth monitoring programs, they are fragmented and nowhere near as comprehensive and integrated as the SRA.

Health Rating	River Valley
Good	Paroo
Moderate	Border Rivers, Condamine
Poor	Namoi, Ovens, Warrego, Gwydir, Darling, Murray Lower, Murray Central
Very Poor	Murray Upper, Wimmera, Avoca, Broken, Macquarie, Campaspe, Castlereagh, Kiewa, Lachlan, Mitta Mitta, Murrumbidgee, Goulburn

Table 1: Sustainable River Audit 2008 (Davies et al. 2008)

Despite the limitation of monitoring there were sufficient data for the 2016 Australian State of the Environment (SOE) report to provide an assessment grade of very poor and deteriorating for the "state and trends of inland water ecological processes and key species populations" (Argent 2016). The SOE report further observes that there is "widespread loss of ecosystem function" in the Basin. The SOE also notes that, in terms of the "state and trends of inland water flows and levels" in the MDB, there has been no Basin-wide improvement since 2011 and that "longer-term downwards trends in flows seen in nearly 50% of stations, with no change in trends evident since 2011" (Argent 2016).

With the SRA discontinued, we are now dependent on limited and fragmented monitoring to assess trends in river and groundwater condition into the future. Will we have evidence to judge the success of our public investment, or is it something we will have to leave to the future? The driver for the water reform was, however, based on reliable, comprehensive evidence that the Murray–Darling River system's health was as set out in Table 1. It was poor or very poor for most of the rivers on which there was substantial extraction.

The poor health was based on the condition in terms of:

- flow regime incorporating volumes, periodicity and variability,
- aquatic plants and invertebrates,
- fish and bird life, as well as
- floods and flow regimes that are necessary for groundwater recharge and particularly for transport of salt from the Basin to the ocean.

A key driver for the impact of water extraction on river health and function is to understand the nature of rainfall variability over the longer term and observe how it was during periods of relative plenty that coincided with the rapid expansion in irrigation and water extraction in the MDB.

In Figure 1, the rainfall anomaly data for the Darling illustrates there is a period pre-World War II and pre-development that is quite different in its pattern to post-World War II and the period of rapid development of the MDB water resources. These two periods are indicated by the horizontal arrows in Figure 1.

The vertical arrows indicate periods of drought in the last 112 years. There were at least four significant droughts pre-World War II and two (see larger arrows in Figure 1) significant droughts since, with quite long periods of wet years, as indicated by positive rainfall anomaly. It was during this post-World War II period with long intervals of positive rainfall anomaly that the expansion of irrigation and water extraction occurred. This is shown clearly in Figure 2, when the water extraction and water storage history is laid over the rainfall anomaly pattern for the same period.

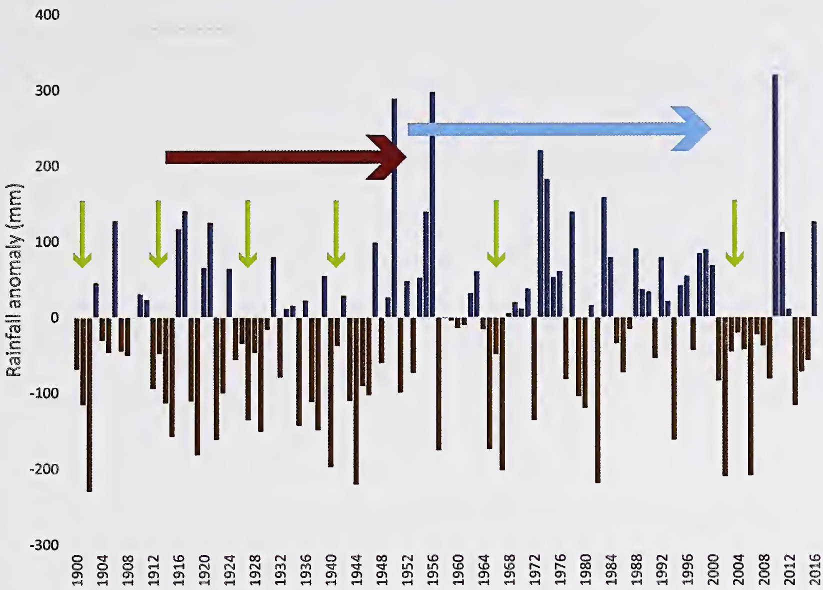

Figure 1: Annual rainfall anomaly in the Murray–Darling Basin, 1900–2012.

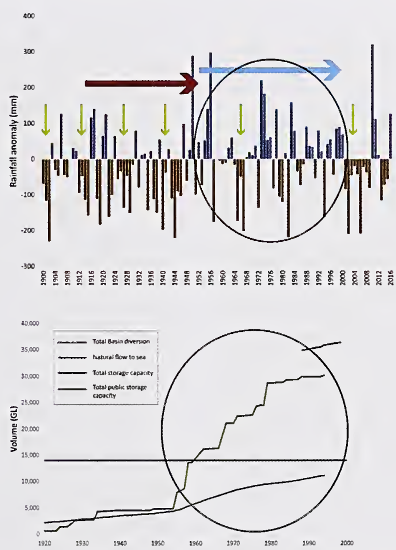

Figure 2: Rainfall anomaly in the Murray–Darling Basin set against the water extraction and water storage over 100 years of history.

Thus we seem to have set up our irrigation over a period that in general was considerably wetter than earlier periods of our history. It was not until 2000–2010 (when the Millennium Drought hit the MDB), that we saw clearly the profound implications to the water security and environmental impact to the level and manner of water resource development. Figure 3 demonstrates the impact of water extraction on river flow regimes.

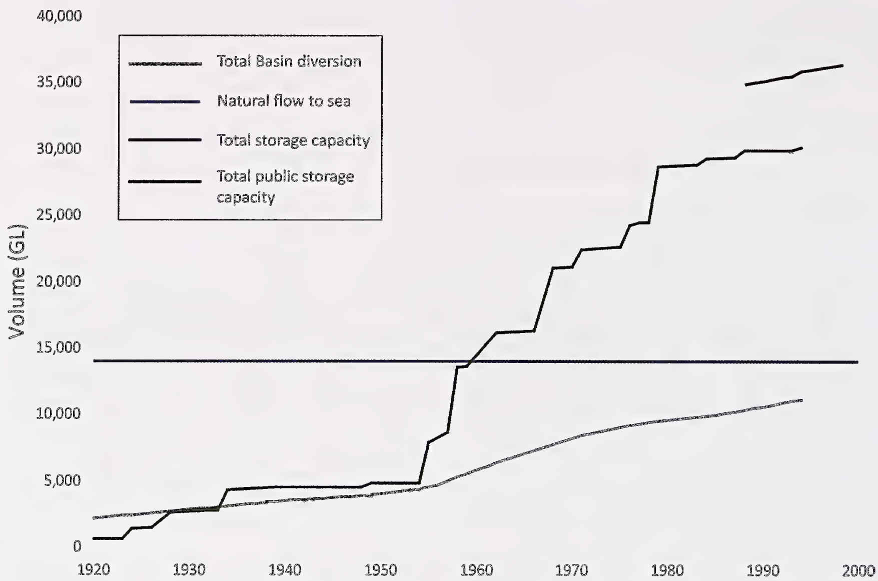

Figure 3: Storage capacity and diversions in the Murray–Darling Basin over time (Chartres and Williams 2006).

The long-term median natural flow from the MDB is about 14,000 GL/year. Since the 1960s, water extraction has steadily increased towards this level while built storage in dams and reservoirs increased rapidly to reach approximately 35,000 GL, or more than twice the annual volume that flowed to the ocean under natural conditions. As indicated earlier, this resulted in flows in the system equivalent to droughts that were now occurring in six out of ten years; compared to one in twenty years under natural flow conditions in which the ecological systems had evolved.

The key message is that to operate in this highly complex eco-hydrology under a highly variable climate, large storages are required. These large storages have a profound impact on the annual flow volumes but, more importantly, on the temporal patterns of floods and droughts within the floodplains, billabongs, wetlands and groundwater aquifers of the river system.

Growth in water use in the MDB since 1920 is set out in Figure 4 and highlights again the rapid increase in diversions from the late 1950s of around 4000 GL/year to over 11,000 GL by 1990. As discussed earlier, in the 1990s it was clear that the river system was stressed through over-extraction, and the evidence of declining ecological health was established.

The response was the historic intervention by the States, through the MDB Ministerial Council in 1994, to place a cap on further extraction beyond 11,600 GL/year. This courageous policy intervention caused enormous political conflict. It was strongly opposed in some quarters, resulting in a large campaign around the slogan "Zap the Cap" during the 1996 Federal election.

While generally Basin communities recognised that extraction had reached a limit, there remained a residual resentment and resistance to recognising that we had taken too much water from the system and we

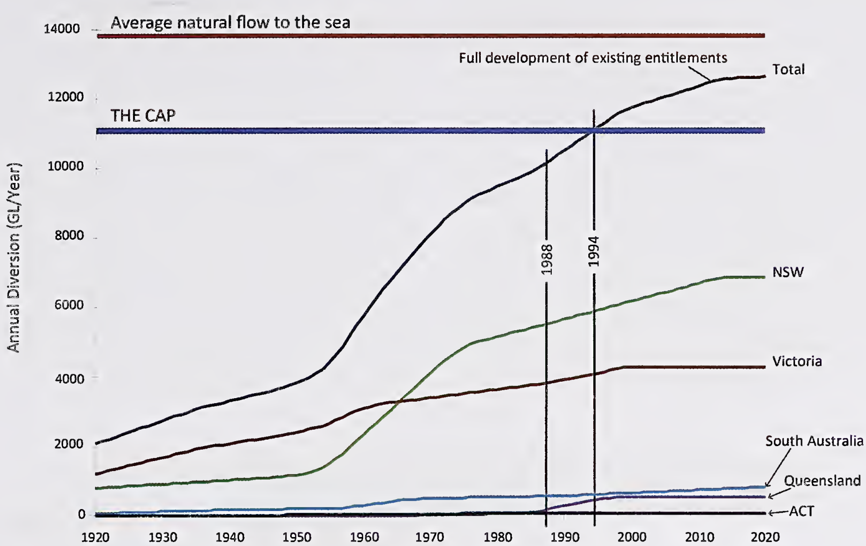

Figure 4: Growth in water use in the Murray–Darling Basin since 1920 (Chartres and Williams 2006).

needed to revisit how we operated. The facts were that available water was heavily used and this left a relatively small volume to service the ecological and hydrological functions of the river and groundwater system upon which healthy rivers derive their life.

It is important to realise that the surface water and the substantive groundwater systems that exist in the Basin are not separate — they are connected. Unless we have the large flows in the river channels and floods on the floodplains where the connections to the groundwater aquifers usually exist, we do not fill up the groundwater systems. Therefore, unless you have the Lachlan flowing and flooding in the north of the Lachlan, you do not have the groundwater in Hillston for our almonds. A flood in one place generates the groundwater and often the base flow in another place. It is a choice of where the water is used. If it is used so there is no flood, then it cannot be used in the connected groundwater. You can only use it once! An Indigenous Elder once said to me: "When you think about water make sure you understand what it's doing, where it is before you move it somewhere else."

It is a critical, fundamental thing. Dams do not make more water — rainfall does. Further, having healthy rivers is not just so we have wetlands with rich fish and bird life. Healthy rivers are importantly about having flows and floods that replenish groundwater and have enough water movement to mobilise the salt that is always part of the Australian landscape, and move that salt to where it originally came from: back in the ocean. That is fundamental to the sustainability of irrigated agriculture in the MDB.

In Figure 5, at Wentworth, NSW, where the Darling River joins the Murray River, we have depicted the natural flows modelled and the observed flows under current water extraction over the 10-year period from 1998. It is clear that the flows are dramatically reduced, particularly in the

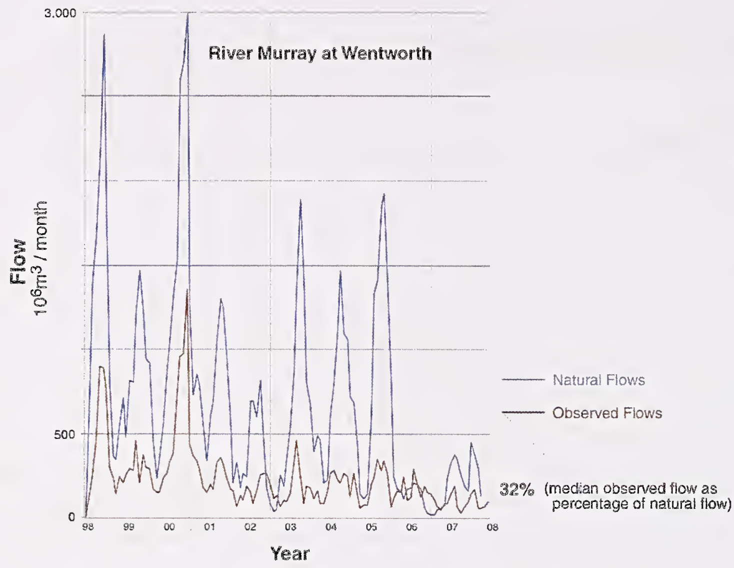

Figure 5: Murray–Darling River flow at Wentworth, NSW, over ten years from 1998 to 2008 (Grafton et al. 2014).

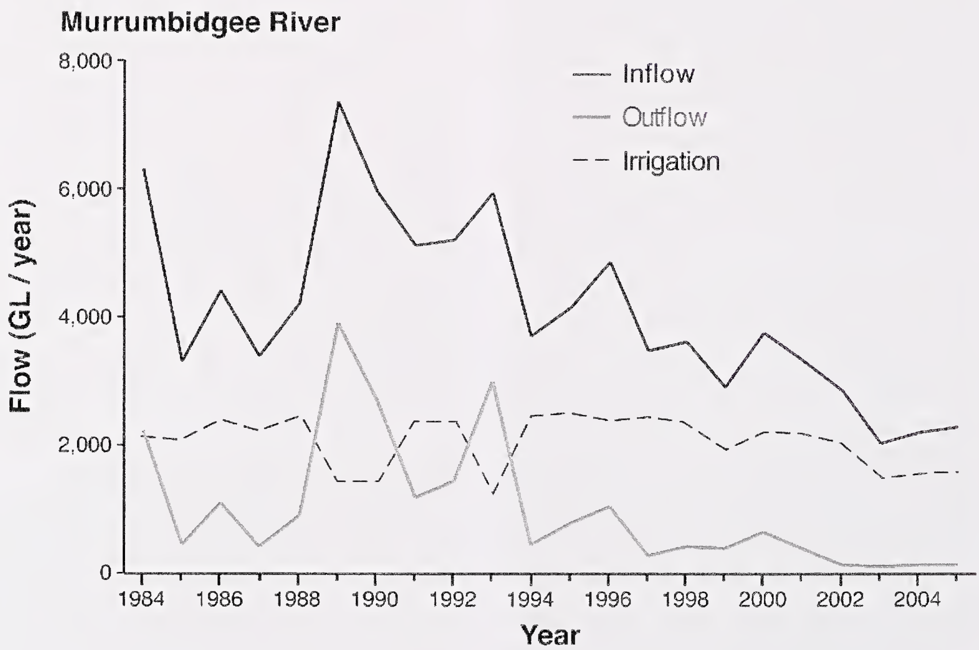

Figure 6: Murrumbidgee River at Balranald, NSW: inflow, outflow and water used for irrigation from 1984 to 2005 (Grafton et al. 2012).

higher-rainfall years. The large and moderate natural flows no longer occur. It is during the Millennium Drought that we see a most profound impact on the flow regimes of the MDB rivers. Severe and frequent droughts are imposed on the rivers and groundwater.

A similar story is told in Figure 6 for the Murrumbidgee system. The flow into the river system is compared to the irrigation usage and extraction with the river flow at Balranald, NSW. The profound impact on the river flow is clearly evident, while the extraction for irrigation is maintained at a relatively constant level despite the high variability of inflow to the river and the overall declining trend during the Millennium Drought. The ecological and hydrological systems of the river bear the full burden of the drought conditions, to yield extreme drought impacts on the river function.

For an overview of the Basin as a whole, Figure 7 shows the mean long-term (115 years) inflows, extractions and the impact of the extractions on the end-of-Basin flows

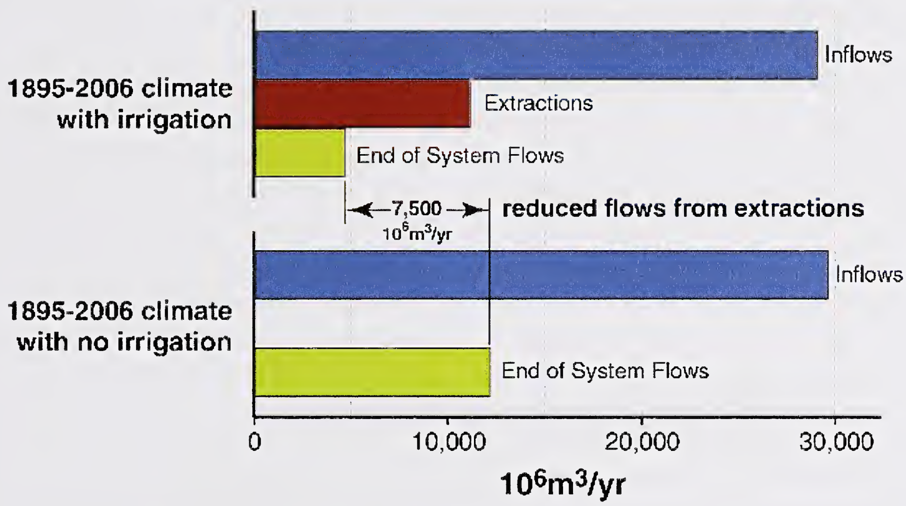

Figure 7: Inflows, end-of-system flows and extractions with and without irrigation for the Murray–Darling Basin from 1895 to 2006 (Grafton et al. 2014). Note: 1 GL = 10^6 m^3.

compared against modelled long-term natural flows where there is no extraction for irrigation. Overall, end-of-system flows are reduced by approximately 7500 GL. However, the consequence is not that simple. There are other factors (beside water flow) that determine river health: flooding, management of feral animals in the water (for example, Carp), and management of grazing systems on our floodplains.

While the graphical data of Figures 5, 6 and 7 tell the story of the profound impact on both the magnitude and pattern of flows in the MDB, Figure 8 attempts to visually show the magnitude of the extraction relative to the natural flow for the Murrumbidgee River. The left image is a supply channel in the Murrumbidgee Irrigation Area; and the right image is the Murrumbidgee River near Canberra during a high-flow event. The large

Figure 8: Image of irrigation supply channel in the Murrumbidgee Irrigation Area compared to the Murrumbidgee River near Canberra. Images © John Williams.

extractions in the irrigation channel relative to the river itself are clearly apparent in these images and reflect the profoundness of the impact to the flow regime of our MDB rivers.

Figure 9 depicts the location and magnitude of the flows within the MDB rivers, gives an overview of where the water is located in the Basin, and provides a glimpse of its complexity. The thicknesses of the river lines reflect the magnitude of the long-term average flow and thus availability.

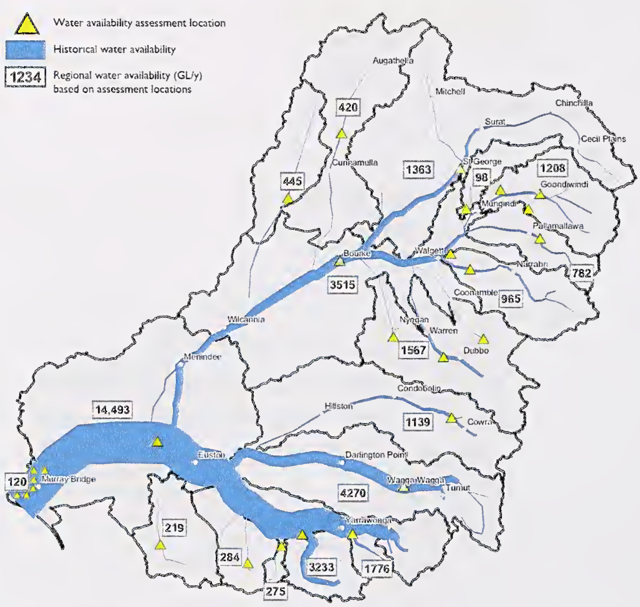

Figure 9: The rivers and water availability in the Murray–Darling Basin (CSIRO 2008, p. 29).

Clearly the major part of the Murray–Darling is the Murrumbidgee and the Murray rivers. Both are largely fed from snow melt and are located in a higher rainfall zone, dominated by winter rainfall. The southern system is more easily managed than the northern system based around the Darling River and its northern tributaries, which are fed by highly variable summer-dominant rainfall patterns where much of the variability is driven by the sub-tropical effects of the monsoon. The result is extensive flooding over large floodplains interspersed by low flows and drought.

The opportunity for dam and reservoir storage in the Darling system is relatively small at 4700 GL, compared to the southern rivers' storage capacity of around 16,300 GL. This further adds to the complexity of management for sustainable irrigation.

The very shallow Menindee cluster of lakes represents the largest storage in the northern Basin of around 1760 GL with an annual evaporation of over 1300 GL per year. The annual variability in the north is very high coupled with a relatively small storage; whereas the south is also high but this is mitigated to some extent by the contribution of snow melt to the flow regime.

Not only is the MDB is a complex biophysical system driven by temporally and spatially highly variable rainfall, which together have shaped the landscape topography in which ecosystems have evolved to accommodate these circumstances to produce a rich and diverse biodiversity that stands tall as a globally important natural heritage. It is also home to 35 endangered species of birds, 16 species of endangered mammals and over 35 different native fish species.

In the MDB, a river is much more than the main channel. Our river is a system of connected floodplains, billabongs, anabranches and nearly 30,000 wetlands. Figure 10 depicts in cross-section the nature and functions of the MDB river system.

Flooding is fundamental to the life of these river systems. Floods connect the main channel to the multiple levels of floodplains, the anabranches, the wetlands, billabongs and backwaters. It is here that water connects to the groundwater aquifers and replenishes them during floods, and in drought and dry times support the red gum forests and provide base flow to the main channel. It is these backwards and forwards flows that drive and nurture the ecological function and, ultimately, the river system health.

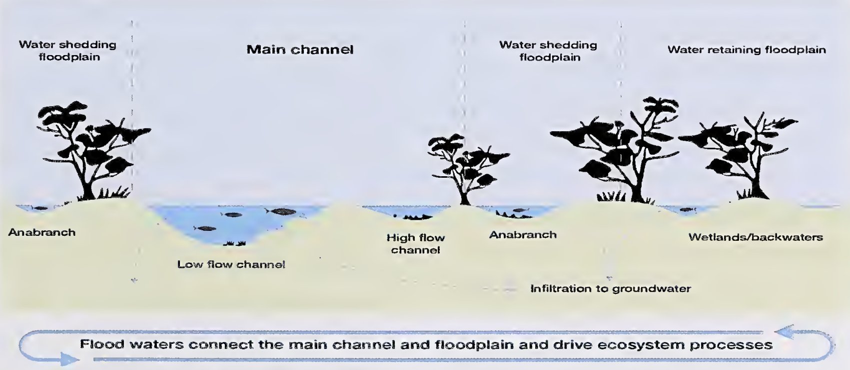

Figure 10: Cross-section of the ecological and hydrological functions in a riverine red gum forest in the MDB (Natural Resources Commission 2009).

Much of the Basin is flat, therefore rivers meander, and anabranches, billabongs and wetlands form. In this river geomorphology, for the river to function as it has evolved, flooding sequences are essential. In order to live, the river system needs to have water flowing out of those main channels into anabranches, billabongs and wetlands. This is where life cycles are re-ignited; food webs and a multitude of ecosystem functions are established. These are the places which drive the health of the river system. Where river metabolism kicks into life; where energy is captured as carbon and nutrients are fixed into emerging ecosystems; where algae, aquatic plants, small crustaceans generate a feed stock; and whole parts of the ecosystem then flow back into the main channel to nurture the aquatic ecology of a healthy main channel. This is the engine room — in some ways the stomach and in some ways the lungs of the river — and if you disconnect a river in the Murray–Darling from its stomach and its lungs, you can expect trouble. That is why over-extraction which significantly changes the flow regimes of the river system requires intervention to recover these functions. This is one of the key issues that we face.

Steps in Basin water reform: how much water is needed to return rivers to a healthy condition?

As outlined previously, in the 1990s, river health was in decline, the cap on extractions was introduced, data were collected, and the best science indicated that large volumes of water needed to be returned to the natural flows of the Basin rivers. Preliminary expert estimates suggested (Jones et al. 2002) at least 4000 GL/year needed to be removed from the volume extracted and that volume returned to the natural flow regime of the rivers. This was a large amount of water when set against the cap of 11,600 GL/year, a reduction in extraction of 35%.

Toward the end of the 1990s, there developed between scientists, senior state and federal officials, and visionary politicians of the time a recognition that water reform was essential. New ideas and innovation would be needed to bring about the magnitude of reduction in water extraction required, as indicated by the emerging science. Following the fierce debates over the establishment of the cap on further water extraction, an accord emerged between the state and federal governments that has often been overlooked but which was fundamental to making the reform happen.

The accord was conceived where public water licences, after being separated from land, were to be converted by the State governments to a tradeable private property right. This water entitlement generated an allocation of water dependent on the seasonal rainfall patterns and storage capacities. In return for this exchange, water would be returned to the rivers by the government purchasing back from willing sellers the entitlement and their allocations to yield healthy working rivers. This was a huge reform and innovation in the development of water policy. It is the central principle behind the policy development within the National Water Initiative (NWI) designed to achieve sustainable water use in over-allocated or stressed water systems. In particular, the state and federal governments agreed:

> … to implement this NWI in recognition of the continuing national imperative to increase the productivity and efficiency of Australia's water use, the need to service rural and urban communities, and to ensure the health of river and groundwa-

ter systems by establishing clear pathways to return all systems to environmentally sustainable levels of extraction" (NWI 2004).

This was the *quid pro quo*. The conversion of a water licence to a tradeable private property right meant transferring a huge amount of wealth from the public sector to the private sector. In fact, the property rights to water are now worth $47 billion in 2012. This was done because it was seen as a just, fair, transparent and socially acceptable means to bring about a very large adjustment in the amount of water which could be extracted from the rivers. The NWI and the subsequent Water Act recognise this principle but it is often forgotten in the public discourse.

How much water is needed to return all stressed and over-extracted systems to environmentally sustainable levels of extraction? That is a challenging question scientifically because returning rivers to healthy conditions is not just about returning a volume of water. There is much complexity in how and when the volume is returned to generate the required flow regimes in both time and space, but, importantly, there are other factors in river and floodplain management which must be addressed, along with the return of water to move rivers back to a healthy condition. As previously indicated, the earliest attempts in 2002 to answer this question used expert panels and it was estimated for the Murray River alone that some 4000 GL/year was required to generate a return to good condition.

In 2008, using the best modelling available, the Wentworth Group (Wentworth Group 2008) concluded that approximately 4350 GL/year would be required. In 2010, the Wentworth Group (Wentworth Group 2010) indicated in more detail that 4400 GL/year was the amount required to generate a good chance of returning the Basin rivers to healthy conditions.

The MDB Authority (MDBA 2010) then published in 2010 the *Guide to the proposed Basin Plan*, which was designed to give people a sense of the scope of the Basin plan. Their work indicated: that 3860 GL/year was the minimum (which had a low likelihood of success in achieving healthy rivers across all the Basin); and to achieve a high likelihood of success, the volume required to be returned to the river was as high as 7600 GL/year. When released, the magnitude of the reform shocked the irrigation communities in the Basin. These communities had never previously been exposed to the magnitude of the reform that was required.

Steps in Basin water reform: determination of a Sustainable Diversion Limit (SDL) for surface and groundwater

The political response to community concerns following the release of the *Guide to the proposed Basin Plan* caused a rethink in the development of the Basin Plan. Added to the biophysical complexity of determining a Sustainable Diversion Limit (SDL) was the complexity of incorporating social and economic analysis and negotiation in the determination. There was a clear recognition that water reform of the magnitude required to return the stressed rivers to healthy conditions had to urgently address the social, economic and community concerns (although it was clear the Water Act gave ultimate priority to the environmental sustainability of the river system).

The work to 2010 suggested that the volume of water sat around a 35% reduction in current levels of extraction and implied a SDL would be approximately 65% of the

current cap (11,600 GL) at approximately 7540 GL/year. The MDBA recognised the need to establish a consistent language and a process to move beyond the work of the *Guide to the proposed Basin Plan*. They adopted a process as set out in Figure 11 for determining a Sustainable Diversion Limit (SDL) in the Basin.

Key in this was the establishment of an Ecological Water Requirement (EWR) derived from the identification of the ecological and hydrological assets and their functions. The MDBA then set about determining the social and economic impacts of reducing current extraction by the EWR along with the legal and engineering/infrastructural constraints of delivering the EWR to the river systems. These are complex considerations and invariably resulted, as far as the published information allows, generally in a much larger SDL than indicated by the EWR.

While the process outlined in Figure 11 is rational, it is an open question as to whether it complies with the intent and purpose of the NWI and the Water Act — both of which gave clear priority to returning rivers to healthy conditions. Unfortunately, the process and analysis used to arrive at the SDL were opaque at best and certainly not open and published in a transparent manner.

The recommended reductions in extractions in the *Guide to the proposed Basin Plan* were revised downwards to 2750 GL/year when the Basin Plan was enacted in November 2012. The science to support this figure is a mystery to me. I do not understand the science, economics, social science or engineering used to arrive at this figure of 2750 GL/year. I have never yet seen the quantitative evaluation of this calculation. This is despite the fact that a study in 2011 by CSIRO (2011, p. vi) concluded that an increase in environmental flows of 3000 GL/year, based on long-term averages, would be insufficient "… to meet the South Australian environmental water requirements" and would also be insufficient to meet the salt export requirements specified by the MDBA.

In fact the lack of an open explanation of the basis for the recommended SDL in the Basin Plan led the Australian Senate Standing Committee on Rural and Regional

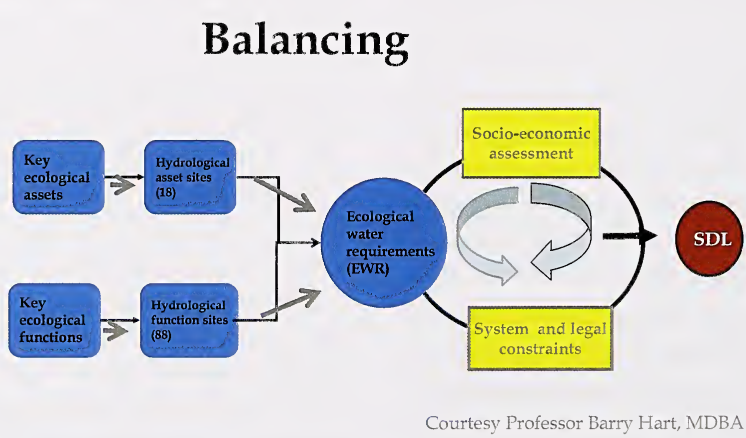

Figure 11: The process and tasks required to establish a Sustainable Diversion Limit (SDL). Kindly supplied by Professor Barry Hart, member of the Murray–Darling Basin Authority.

Affairs and Transport Inquiry into the Management of the MDB in March 2013, to recommend the MDBA provide a "concise and non-technical explanation of the hydrological modelling and assumptions used to develop the 2750 GL/year return of surface water to the environment within the Basin Plan."

The Senate findings (The Senate 2013) supported the disappointment and concerns I have on the size and nature of the SDL recommended and adopted in November 2012, when the Murray–Darling Basin Plan was enacted to give effect to the *Water Act 2007*. In December 2012, after further analysis and debate, it was negotiated that the 2750 GL return of environmental water to the river system should be increased by 450 GL to 3200 GL, provided funding of $1.7 billion of new money could be found for this 450 GL of additional environmental water.

It is important, at this point, to appreciate that the SDL is computed by first ascertaining the Baseline Diversion Limit (BDL) established in the Basin Plan for the entire Basin. Then the SDL is equal to the BDL less the water to be returned to the environment, which is the 2750 GL/year, or, if funds allow, 3200 GL/year. The BDL was established at 13,623 GL/year (MDBA 2012, p. 28) and exceeds the annual total volume of surface water extracted in the Basin in any year from 2000 to 2001 through to 2014 to 2015, or in any year prior to setting of the cap (11,600 GL/year) in 1995. The BDL was calculated by adding to the traditional extractions of 10,636 GL/year and stream diversions of 267, the interception of plantation (2384) and farm dams (336) to yield 13,623 GL/year. Setting a BDL at such a high level has the net effect of increasing the reliability of existing water entitlements in terms of their long-term average water allocations, but reducing the effectiveness of water recovery in terms of increasing environmental flows.

By increasing the Baseline Diversion Limit by 2720 GL/year (2384 + 336) above what it was, and then reduce this by 2750 GL/year would appear to be an exercise in smoke and mirrors. What have we really done?

Nevertheless, this is the situation. The planned reductions in extractions and returns to the environmental flows result in a planned SDL for the Basin of 10,873 GL/year. Recall that the cap in 1995 was set at 11,600 GL/year. Have we in reality only reduced the extraction beneath the cap by 727 GL/year? Now let us consider the groundwater story.

While the Basin Plan intended to reduce permissible surface water extractions by 2750 GL/year, it actually increases permissible groundwater extractions by 1548 GL/year (Pittock et al. 2015), from 1786 GL/year to 3334 GL/year based on long-term averages. This is despite the fact that surface and groundwater are highly connected in the Basin and that increased groundwater use lowers base flows to rivers (Evans 2004). The science and analysis to justify this very significant increase is not available for scrutiny and public explanation. It has not been subject to open, transparent peer review. Once again mystery surrounds another key plank in the Basin Plan. Therefore on paper we have reduced the surface extractions but we have increased the groundwater extractions.

At this point in time, the pattern of water reform in the Basin appears as follows.

As of June 2016, the Commonwealth Environmental Water Holder indicated that

approximately 1981 GL of the 2750 GL had been recovered for the environment, of which about 1165 GL of entitlement was purchased by tender from willing sellers, and approximately 602 GL has been calculated to arise from infrastructure and water use efficiency projects and from State Government assignments.

Issues arising from complexity at the interface of biophysical, social and economic systems

The diagram in Figure 12 should help to put this complexity into perspective. The task ahead is first to implement water policy reform which ensures the health of river and groundwater systems by establishing clear pathways to return all systems to environmentally sustainable levels of extraction. That is complex in itself, but the task must also include measures that achieve this whilst managing the economics and social impacts of the water reform. It is clear now — and it was to some in 2010 — that you cannot take 3200 GL of water (a 23.5% reduction) out of the irrigation system without social and economic consequences. No environmental reform can ever, in my view, be implemented without consideration of the tasks to manage the social and economic impacts of change. The MDB is no different. Yet we have attempted a major water reform with little attention given to the management of the social and economic impacts (other than to back away from the objective of the water reform if there is an economic impact).

The complexity of the MDB can be visualised with at least three complex systems interacting together which will ultimately determine the environmentally sustainable level of extraction. First, the biophysical nature of the rivers, groundwater landscapes and their embedded ecosystems will interact to yield the EWR. Second, the Social and Economic Systems (SES) which have evolved to utilise and redistribute the water, land and ecological resource. Third, the natural and built infrastructure, collectively a complex system of engineering, policy, legal and management yielding Infrastructure System Constraints (ISC) to allow water to be delivered to the hydro-ecological assets.

The river system that has been designed for irrigation (built infrastructure of dams, reservoirs, weirs, channels, roads and bridges), will seriously constrain the delivery of water to floodplains, billabongs and wetlands as in natural flows. The built infrastructure on the floodplains are very significant constraints to returning natural flows and func-

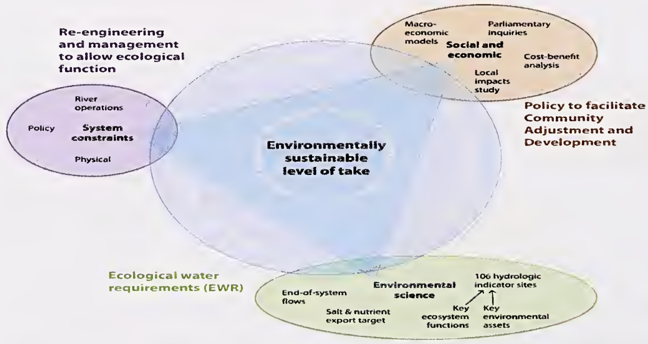

Figure 12: The complex system of the MDB into which the water reform task is cast. Kindly supplied by Professor Barry Hart, member of the MDBA.

tions essential to healthy river functions (see Figure 10).

A key task is the re-engineering and management to allow ecological function. For water reform policy to be effective, it must address the management of at least these three interacting complex systems. No wonder the struggle has a long history.

Given this understanding of the complex system, what progress has been made to date?

Since the publication of the *Guide to the proposed Basin Plan*, any evidence of a transparent scientific analysis and synthesis to provide a defendable prediction of the EWR as a means of determining the SDL has been abandoned. The science leading to the prediction and establishment of the EWR has, in my view, not been done in a way that is open to scrutiny. Obviously the political judgements will come as you put the three parts of the triangle together (see Figure 12), but first the science underpinning the EWR estimate and its likelihood of generating healthy ecological conditions for the rivers must be transparently provided. Let us get the science clear so we know what the risks are that we are working with in order to then make social and economic choices.

ISC are still to be resolved. How do we flood private land — and often public infrastructure — in order to have wetlands and billabongs begin to function again? Investment in re-engineering to minimise these constraints and maximise the re-establishment of natural flow patterns in the landscape has not received the attention it requires.

Social and economic analysis is required to inform policy development in order to assist communities to accommodate the Ecological Water Requirement. The volumes of water required to be returned to the rivers are large, at approximately 25% of current extractions. Therefore economic adjustment and social impacts can be expected to be significant and require community development and adjustment interventions.

The 2010 Wentworth Group statement (Wentworth Group 2010), built on research conducted by The Australian National University, outlined the importance of recognising that regional and local community adjustment and development would be necessary if approximately 4000 GL/year was returned to the river system. Their report stated: "The scale of the water reform to restore the health of rivers, wetlands, floodplains and the estuary in the MDB is daunting. It can only be achieved by working with the communities of each catchment affected to bring about these reforms." An environmental reform of this order must have a pathway to manage the actual social and economic impacts.

The economic impact of a 30% reduction in extraction was computed to be approximately 10% across the whole Basin. But in the Murray and Murrumbidgee rivers, which hold most of the water entitlements, the economic impact was computed to be approximately 12% and 25%, respectively. These are not economic impacts that can be accommodated without active policy and regional development programs to assist community adjustment.

Unfortunately, the Basin Plan did not have any policy or program of the magnitude and form appropriate for the task. However, the Wentworth Group (2010) did point to a policy option which focussed on water purchase to obtain water entitlements which were returned to the river. A large proportion of the "Water for the Future" program funds could be devoted to provide

financial assistance to the communities in the Murray–Darling catchments, such as investments in public infrastructure to help adjustment to a future with less water.

The School of Social and Policy Studies at Flinders University has developed the "Thriving Communities" model (Miller and Verity 2009; Miller 2011) based on an inclusive social and economic development approach. This model could provide the basis of this community development approach whereby the level of funding available to each affected community would be based on the economic impact resulting from the withdrawal of water for consumptive use in that district. In some of the worst affected communities, these amounts would need to be significant. With this financial support, some communities might decide to move out of irrigation and branch into new industries. Others might prefer to consolidate their irrigation industry and use the funds to invest in new water technology or to add value to their products. However, this decision would be made for the benefit of the whole community, not just individual irrigators.

In the current implementation of the Plan, funds flowing from the direct purchase of water entitlements are for much smaller amounts than where most funding is allocated, mainly for the refurbishment of principally on-farm infrastructure to increase Water Use Efficiency (WUE). The consequence is that practically all funds go to irrigators and thus to only one sector of the community which is confronted by the adjustment to the water reform impacts.

The complexity resulting from the interaction of the three systems depicted in Figure 12 makes water reform policy in the Basin a very demanding task indeed. My impression is that the policy development as reflected in the Basin Plan and its resourcing and implementation through the "Water for the Future" program has struggled with this complexity and is yet to find the ways and means to bring it together.

The evidence at hand is that the understanding of the three systems has been less than adequate and neither have the systems been subject to open transparent analysis. The science underpinning the EWR has been disappointing; the clarity and transparency of the socio-economic examinations have lacked depth and consistency and have not adequately informed a policy to drive the significant regional and community adjustment and development required; and the attention to the legal operation management of ISC was not recognised early in policy development and has yet to be resourced adequately to drive effective delivery of the EWR.

The policy options for returning water for river and groundwater health

Two policy options to obtain water for return to the river and groundwater were: first, a direct purchase of entitlement and allocations from willing sellers; and, second, of water recovery through infrastructure subsidies and supply measures.

Until 2014, the Australian Government spent approximately A$2.3 billion acquiring water entitlements from irrigators using reverse tenders, but such purchases have now been halted (Hunt et al. 2015). The average cost to the Australian Government of acquiring such water entitlement purchases has been about $2000 per megalitre (and in some instances as low as $884 per megalitre). This is much less than the costs from acquiring water through infrastructure subsidies (Grafton 2017).

Consequently, the cost to the Australian Government to acquire the 2750 GL/year required under the Basin Plan entirely from the purchase of water entitlements would have been approximately $5.5 billion, while currently it is projected to spend $8.9 billion to achieve the same volume of water recovered through the increased use of infrastructure subsidies and supply measures (Grafton 2017) operating both on- and off-farm, such as the Sustainable Rural Water Use and Infrastructure (SRWUI) initiative under the "Water for the Future" program.

As stated by Grafton (2017) it is now very clear "Notwithstanding the effectiveness of water recovery through infrastructure subsidies and supply measures, the economics of such an approach is highly questionable." For instance, according to the Productivity Commission, the "…Australian government may pay up to four times as much as recovering environmental water through infrastructure upgrades than through water purchases. In other words, a premium of up to $7,500/ML may be paid for recovering water through infrastructure upgrades…" (Productivity Commission 2010, p. 129).

Despite this evidence, the direct purchase of water entitlements by the Australian Government has been halted and "Water for the Future" funds are now used almost entirely for water recovery through infrastructure subsidies and supply measure programs. While many irrigators claim that such purchases negatively affect both irrigators and their communities, the evidence is contrary to these claims in that direct purchase of water entitlements by willing sellers increases, rather than decreases, the gross domestic product in the Basin (Wittwer and Dixon 2013).

As shown by Grafton and Jiang (2011), even with very large reductions in surface water extractions (30%), such buybacks from willing sellers impose very much smaller decreases (1–2%) in the gross value of irrigated agriculture and also irrigation profits. This is because water trading between regions in the Basin provides an effective way to mitigate reductions in surface water extractions (Grafton and Horne 2014; Kirby et al. 2014). The benefits of trade can be very large, approximating $1.5 billion in 2007–08 during the worst year of the Millennium Drought (National Water Commission 2012, p. xii).

Figure 13 sets out the hydrological flows between the farm and the hydrology of the landscape. It demonstrates that gains in WUE cannot lead to increased water recovery unless the volume of water extracted is decreased by a greater amount than the reduction in water losses in surface and drainage past the root zone. Gains in WUE must result in a reduction in return flows to the landscape hydrology unless the subsequent reduction in extraction exceeds the losses or return flows. This is captured in Figure 13, where the numerical example for most irrigation is set out. If WUE is able to reduce return flows of 30 units to zero, under current agreements, then half of the return flows (30 units) are reduced in volume extracted from 100 to 85 units.

Overall, the consequence is that returned flow is halved, from 30 to 15 units. This is well-recognised in the literature (Batchelor et al. 2014; Adamson and Loch 2014; Qureshi et al. 2010) and noted by the Productivity Commission (2006, p. 171), "Capturing return flows that contribute to downstream allocations, for example, does not create overall system savings," yet is not appreci-

ated or recognised in the water reform policy of the Basin Plan.

In short, the dependence in the Basin Plan on water recovery through infrastructure subsidies and supply measures to yield WUE improvement is fundamentally flawed. Not only is it more costly than direct purchase of entitlements, it cannot deliver water recovery as advocated because it is based on fundamentally flawed hydrology.

However, it is more complex, as the surface drainage and drainage losses beneath the root zone from irrigation become increased

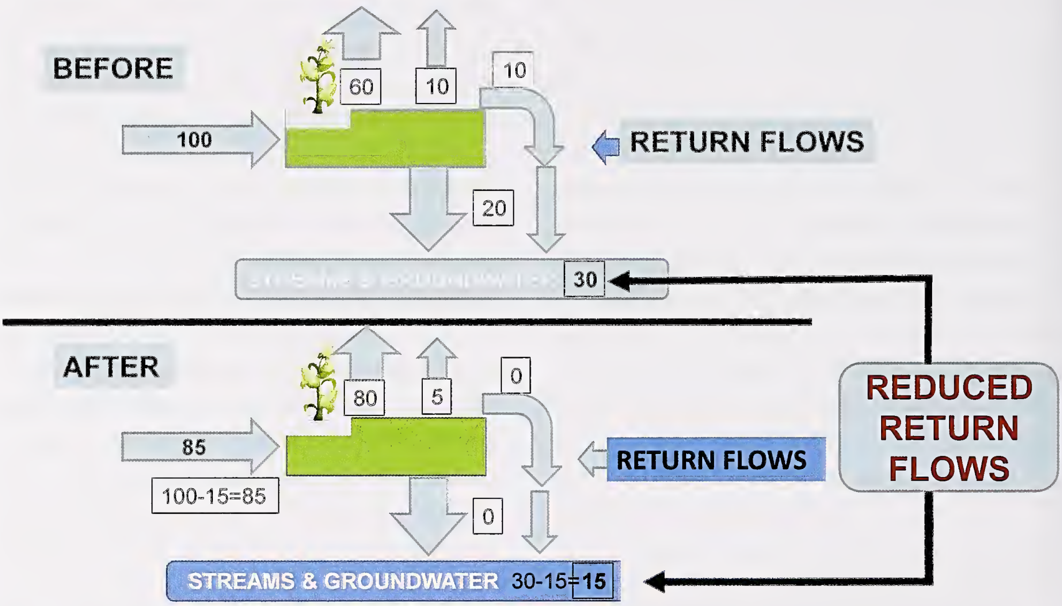

Figure 13: Water use efficiency gains, return flows and reductions in extractions.

return flow to rivers, streams and groundwater aquifers as depicted in Figure 13. These flows in some geological settings can be detrimental to the quantity and quality of environmental flows. Leakage and losses from irrigation water usually pick up salts, nutrients (especially nitrogen), and agrochemicals, which can drive salinisation and the pollution of water systems. Therefore, what is required for the future is the establishment of long-term water sustainability targets (ATSE 2017) for irrigation, recognising that farm and landscape hydrology is always connected and the whole-of-system must be examined.

Impact on Murray River mouth and environmental outcomes

Evidence of lack of progress to date, in terms of environmental benefits in the Basin, is provided in the 2016 Australian State of the Environment (SOE) Report that was published in March 2017, and which includes a specific report on inland water. Its findings on the MDB are for the period since 2011 and deliver an assessment grade of very poor and deteriorating for the "state and trends of inland water ecological processes and key species populations".

The SOE Report further observes that there is "widespread loss of ecosystem function" in the Basin. The SOE Report also

notes that, in terms of the "state and trends of inland water flows and levels" in the MDB, there has been no Basin-wide improvement since 2011 and that "Longer-term downwards trends in flows seen in nearly 50% of stations, with no change in trends evident since 2011." Further, Grafton (2017, Figure 3) provides evidence that there is, as yet, no discernible change in surface water diversions within the Basin despite the fact that there have been expenditures, to date, of more than $5 billion under the "Water for the Future" program, and the Australian Government is more than 60% towards achieving its target of reducing extractions by 2750 GL/year.

The evidence at hand is that water application rates also follow a similar pattern, such that the average volume of water applied per hectare was the same in 2014–2015 as it was in 2002–2003 at the onset of the Millennium Drought (Grafton 2017). However, Roth et al. (2013) report that for cotton, the whole-farm irrigation efficiency index improved from 57% to 70%.

Despite the very large expenditure by the Australian Government on water recovery (A$5.3 billion), the failure to see Basin-level reductions in surface water diversions is a matter of serious concern and one that needs investigation. It appears we have a huge failure in public policy.

In Figure 14, the mouth and estuary of the Murray River are pictured: in 2003, in the midst of the Millennium Drought; and in 2016 after several years of above average inflows to the Murray–Darling Basin (see Grafton 2017, Figure 3). In two very wet years (2012/13) the Murray River mouth did not remain open without an intervention of dredging at the mouth.

The Basin Plan seeks to ensure that the mouth remains open without the need for dredging 95% of the time under the 3200 GL water recovery scenario, which is expected to be achieved by 2019. The mouth was again facing the risk of closure during the summer of 2014/15.

In 2014, the MDB Ministerial Council provided $4 million for a dredging program. The Australian and South Australian Governments are currently dredging sand out of the Murray Mouth to ensure it remains open. This process has been underway since January 2015, and will continue for at least another year in order to maintain the opening, and subsequently, the health of the mouth.

By mid-April 2016, almost 1.2 million cubic metres of sand had been dredged. This has resulted in a net reduction of sand at the mouth of 241,000 cubic metres. Recent barrage releases have scoured a modest amount of sand, but sufficient to improve connectivity of the Murray Mouth in the short term. Towards the end of 2016 (see image taken on 2 November 2016 in Figure 14), dredging was halted and the Murray River actually was flowing to the sea in what was a very wet year. At best it is an open question as to the environmental benefits of the huge public investments.

Conclusions and some ways forward

The MDB is a biophysical system driven by a highly variable climate that is in itself complex enough. However, within it exist social, economic and governance systems that regulate the built infrastructure and the legal and operational management of the rivers and groundwater. Together these three intersecting systems yield a highly complex system that is the MDB.

Figure 14: The Murray River mouth in 2003 and 2016 (Department of Environment, Water and Natural Resources 2015). Source: http://www.naturalresources.sa.gov.au/samurraydarlingbasin/projects/all-projects-map/keeping-the-murray-mouth-open

The first step into the future is to recognise and seek to understand the complexity of the Basin.

For public policy in water reform to succeed into the future, the interconnection and interactions of at least these three systems will need to be managed in an integrated manner.

For water policy to achieve the vision of the NWI and the Water Act, all three must receive active attention in policy development and implementation.

The magnitude of the reduction in water extraction is large at 3200 GL/year, and if the science we do have is correct, the volume required appears to approach 4000 GL/year. This reduction in extraction will require a rethink of funding allocations so that regional and community development towards "thriving resilient communities" is adequately resourced to adjust and build new futures. Funding needs to be re-allocated from subsidies for on-farm water use efficiency and supply measures to the direct purchase of entitlements. This will release funds within current budgets to be put towards programs that facilitate and underpin community adjustment, redevelopment and new enterprise. The level of funding available to each affected community would be based on the economic impact resulting from the withdrawal of water for consumptive use in the district. In some of the worst case communities, these sums would be very significant (Wentworth Group 2010).

The governance and implementation has been top-down, and while consultation has been significant there has been resistance, particularly from central agencies, to empowering regional, local and community bodies — such as Catchment Management Authorities and Regional Development Agencies. Such agencies could take responsibility for driving the social and economic adjustment, together with the development and implementation of the water-sharing plans directed to return rivers and groundwater to healthy conditions.

Connell and Grafton (2011) argue that empowerment and engagement with stakeholders, other than irrigators, have been inadequate. They maintain that meaningful participation by Basin communities should include elected regional bodies which would make the decisions about how and when to use the publicly owned environmental water, based on long-term averages, for the purpose of increasing environmental flows and

to generate healthy working rivers. There is evidence that integrated catchment planning, building on resilience principles, can work to empower people to own and manage regional and local environmental assets (Natural Resources Commission 2012; Williams 2012). Such participation, as argued for by Connell and Grafton (2011), would be consistent with "citizen power" rather than "tokenism" (Arnstein 1969) that typified many of the interactions in the processes leading to the Basin Plan (Mulligan 2011).

There are ways of providing empowerment and support to assist people in building new, thriving communities, enterprise and social wellbeing. There are towns in the Murray–Darling which, through their own initiatives, have shown how to be more economically thriving and not so dependent on a water system that is as climatically-driven as this one.

For public policy in water reform to succeed into the future, we must address what has evolved in the MDB. Essentially we encouraged people in the Murray–Darling to adopt irrigated agriculture in one of the most highly variable climates on the planet, dependent on that water, and, at the same time, producing commodities which are subject to the large fluctuation in price on global markets with declining terms of trade. That is a tough gig. It is an example of the very complex systems in which water reform is critical to the long-term sustainability. Yet its success is dependent on policy, governance, and implementation to manage not only the water, but to resource and facilitate the communities to build new and better futures that draw on the multiplicity of uses for the water in rivers and groundwater that support a very diverse array of ecosystem services.

Australians are spending over $11 billion on the Basin Plan. It is a complex system in public policy and we are only in the middle of it. We must rebuild and radically adjust the Basin Plan.

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Communicating genomic complexity

Paul E. Griffiths*

Department of Philosophy and Charles Perkins Centre, University of Sydney, Sydney, Australia
Email: paul.griffiths@sydney.edu.au

Abstract

The field of public understanding of science has long rejected the 'deficit model', according to which the aim of science communication is to bring the views of the public into line with those of experts. However, the shortcomings of public understanding of genetics and genomics remain the focus of considerable concern in the history and philosophy of biology. I argue that these concerns should not be tarred with the same brush as the deficit model. They do not result from privileging the representations of scientific experts, but rather from substantive concerns about the scientific content that is being communicated, and with 'deficits' in both expert and public understanding. History and philosophy of biology and public understanding of genetics research need to be integrated to yield a deeper understanding of the problem of communicating—and formulating—the complexity of genetics and genomics.

Introduction

A large body of research documents limited public understanding of the complexity revealed by contemporary genetic and genomic research. A recent nationally representative survey of adults in the United States found that 76% incorrectly believed that "single genes directly control specific human behaviors" (Christensen et al. (2010), 470). Findings like this suggest that there is a problem with public understanding of genetics and genomics, and historians and philosophers of science have frequently argued as much (e.g. Nelkin and Lindee 1995, Oyama 1985, Keller 1995). However, researchers who specialize in studying the public understanding of genomics disagree, arguing instead that laypersons have "a complex, informed understanding of genetic research, albeit a non-technical one" (Bates et al. 2005, p 331). The lack of a technically correct understanding is not enough to show that there is a problem: "Just because the public does not have a highly technical background does not preclude them from making sensible judgments about genetic science and genetic technology. A person can drive a car perfectly well without understanding the physics of internal combustion or body shell design. These drivers are also allowed to express opinions on where roads should go, what the speed limit should be, and the relative importance of pollution, accidents, and noise to automotive policy" (Bates 2005, p 61). These remarks reflect a longstanding consensus amongst science communication researchers that the adequacy of public understanding of science cannot be reduced simply to the degree to which laypersons agree with scientific experts. Here I argue that ideas from these two research fields—history and philosophy of science and public understanding of science—can be integrated to yield a deeper understanding of the problem of communicating genetic and genomic complexity.

I will not address in any depth here the exact sense in which contemporary genetics and molecular biology is a complex systems science (Griffiths and Stotz 2013). Instead, consider only the nematode worm *C. elegans*, a tiny organism with around 13000 genes and 1000 cells, of which 300 are neurons, deliberately chosen as a simple and tractable model organism in which to elucidate the basic principles by which genes give rise to phenotypes. As Kenneth Schaffner (2016) has pointed out, in the worm we see that many genes are involved in the development of each neuron; that many neurons are involved in each behaviour, and that these circuits frequently overlap; that any one gene is involved in the genesis of many neurons and can affect many behaviours, as can any one neuron; that the process by which genes act to wire together the neurons is stochastic rather than deterministic; and that the worm's environment has a large influence on both the development of neural networks and the behaviour produced by those networks. This is a far cry from discovering a 'gay gene' or a 'gene for adultery' and yet it is unlikely, to say the least, that the genetics of these human phenotypes is any less complex than that of feeding behaviour in the worm.

Public understanding of science

A defining moment in the emergence of public understanding of science as an academic field was the Bodmer Report, *The Public Understanding of Science*, released in 1985 by the Royal Society (Bodmer 1985). The report's focus on improving 'scientific literacy' carried the implication that the public was deficient in scientific knowledge and understanding (Durant et al. 2000). Public understanding of science has traditionally been measured using surveys of representative samples of the general population that assess factual scientific knowledge and self-declared attitudes towards science. They consistently reveal that, "If modern science is our culture's greatest achievement, then it is one of which most members of our culture are very largely ignorant" (Durant et al. 1989, p 13).

The idea of the 'deficit model' came to prominence in the early 1990s, and the model was criticised at the same time as being explicitly formulated (Wynne 1991, Ziman 1991, Silverstone 1991). These influential critiques of the deficit model make several points. The model misrepresents science, portraying it as an unproblematic body of knowledge. The deficit model misrepresents the communication process by treating the audience as passive recipients of scientific information. The standard of success for science communication in this model is the extent to which public understanding mirrors expert scientific understanding. The model "isolates science from contexts that give it public significance" (Gross 1994, p 7) and ignores the fact that the public can access other sources of information, not just through the media, but through local knowledge, practical understanding and common sense (Silverstone 1991). Additionally, the deficit model has been criticised for overlooking the fact that "a great deal of scientific knowledge is both remote from and largely irrelevant to everyday life" (Durant et al. 1992, p 162). Rather than representing a deficiency, public ignorance of science may reflect a sensible allocation of limited time and cognitive resources.

These and other criticisms of the deficit model created pressure for new forms of empirical research into public understanding of science. Mass surveys predominantly

measure factual knowledge about science and neglect other information that contributes to the public's comprehension of specific issues (Bates et al. 2005, Bates 2005). These surveys pay little attention as to why people might want to understand science, and what they may wish to know about science (Turney 1995). These issues can be investigated using more qualitative methods, such as participant observation, longitudinal panel interviews, structured in-depth interviews, and focus groups. A large body of research of this kind now exists, a significant proportion of which is concerned with the public understanding of genetics in particular. Meanwhile, the deficit model has been replaced by a 'constructivist' model in which laypersons construct their knowledge of science from multiple sources in a way driven by their own needs and interests. The public does not just 'soak up the facts' from scientists or the media, "but retain a healthy skepticism about the source of expert knowledge as well as about that knowledge itself" (Cunningham-Burley 2003). While they may not have technical knowledge of genetics, "the public articulates complex understandings of genetic research" (Bates et al. 2005, p 340) drawing on multiple sources of information and understanding.

Historians and philosophers of biology on the public understanding of genetics

The controversy surrounding the very idea that public understanding of science is deficient has not had much impact on the history and philosophy of biology. In this field it is assumed that inadequate understandings of genes and gene action are common, and discussion centres on how to improve the situation (e.g. Oyama 2000a, Keller 2000, Morange 2001, Moss 2003, Kitcher 2003, Robert 2004). The distinguished historian of molecular biology Michel Morange even titled a book *The Misunderstood Gene*. But whereas the deficit model is concerned with the gap between scientific understanding and public understanding, these authors are concerned with deficient understandings shared by scientists and publics alike. This deficient understanding is *successfully* communicated to the public.

The dominant theme in this literature is the need to combat overly simple views of genes and gene action, commonly referred to as 'genetic determinism'. It is important to note that this label is used rather differently from the way it is used in public understanding of genetics. 'Genetic determinism' in history and philosophy of biology is the view that the relationship between genotype and phenotype is insensitive to variation in the developmental environment, at least within the normal range of such variation (Kitcher 2003). In the public understanding of genetics literature, however, 'genetic determinism' refers to the much stronger view that a genotype inevitably destines its bearer to a phenotype (Condit et al. 1998, Condit 1999b esp. 99ff). Thus, while rhetorician Leah Ceccarelli describes the "*nondeterminist* and overly optimistic belief that we can easily change our fate with a simple alteration of our genetic blueprint" (Ceccarelli 2004, p 93, italics added), authors in history and philosophy of biology would see this as belief in genetic *determinism*, because it anticipates that the results of such intervention will be predictable, rather than dependent on details of the genomic and environmental context. The stronger version of genetic determinism might better be called

'genetic fatalism'.[1] Determinists believe that the totality of causal factors at a given time uniquely determines the future. If some of those factors were to change, however, the future would likely change too. In contrast, fatalists believe that the future is determined so that no changes in the present can affect it: if you see Death in the marketplace and ride to Damascus to escape him, Death will meet you in Damascus. Public understanding of science research suggests that the public are not genetic fatalists (Condit 1999a, Condit 1999b), but they may still be genetic determinists.

Genetic determinism is a matter of degree, in the sense that the pattern of interaction between genetic and environmental factors may be genetically deterministic in some cases and not others (Kitcher 2003). It is relatively uncontroversial to claim that the most practical prospect for treating some currently incurable heritable diseases is gene therapy, although that is a genetic determinist view of those diseases. But it is extremely controversial to argue that no practical environmental intervention can eliminate the differences in educational outcomes between ethnic groups in developed countries, or greatly alter the proportion of men and women who achieve prominence in the sciences. So the objection is not to genetic determinism *per se*, but to a blanket presumption of genetic determinism for a wide range of human characteristics.

Finally, it is important to note that the alternative to genetic determinism for authors in the history and philosophy of biology is not an equally implausible environmental determinism but the 'interactionist' view that for many and perhaps most phenotypes there are both genetic and non-genetic factors that are practical sites of intervention to change those phenotypes (Kitcher 2003).

An important theme in these critiques of genetic determinism is the effect of the dominant informational metaphors used both within biology and in popular presentations of biology. The current dominance of these metaphors cannot be overstated (Nelkin and Lindee 1995, Condit 1999b, Griffiths 2001). There is nothing unusual about the following journalistic summary of what we have learnt since Crick and Watson:

> An organism's physiology and behaviour are dictated largely by its genes. And those genes are merely repositories of information written in a surprisingly similar manner to the one that computer scientists have devised for the storage and transmission of other information… (*Economist* 1999, p 97).

Historians have examined how informational metaphors entered biology from a specific cultural milieu in the 1940s and early 1950s (Keller 1995, Kay 2000). The resulting metaphorical landscape actively shaped the way in which biology developed from that time onwards. Historians and philosophers have suggested that the metaphorical landscape of information is not adequate to represent what contemporary biology has accomplished. It introduces some systematic biases into both popular and scientific understanding of those accomplishments of modern biology (Sarkar 1996, Robert 2001, Griffiths 2006). The consequences of uncritical acceptance of informational descriptions of genomics like that quoted above are not restricted to the various extra-scientific publics, but very likely affect biology itself

[1] Richard Dawkins calls it genetic Calvinism (Dawkins, R. 1982, *The Extended Phenotype: The long reach of the gene*, Freeman, San Francisco., p 11).

through a feedback relation between popular science and the future direction of science whose importance has long been recognized (Fleck et al. 1981 [1935]).

Two approaches to analyzing metaphors in genetics and genomics

A number of authors have advocated the replacement of the metaphor of the genome as blueprint in public discourse with the metaphor of the genome as recipe (Hubbard and Wald 1993, Nelkin and Lindee 1995). They have suggested that the recipe metaphor will produce a less deterministic understanding of gene action. This prediction has been empirically tested and rejected by Condit and collaborators (Condit and Condit 2001, Condit et al. 2002). They show that both recipe and blueprint metaphors activate a range of associations in audiences more diverse than those anticipated by advocates of the recipe metaphor. Some subjects understand the 'recipe' metaphor *more* deterministically than the blueprint metaphor; others understand the two metaphors primarily via their existing religious belief system, so that the main issue for them becomes the match between each metaphor and their image of the Creator. Condit et al.'s textual analysis of the actual use of the recipe metaphor in popular science writing reveals that it is deployed in the context of an existing understanding of genetic causation, and in association with a range of other metaphors, in such a way that it becomes merely another way to express the existing understanding of what genes do in the construction of phenotypes. A focus group study produced a similar result — the recipe metaphor was interpreted in such a way as to remove the associations intended by its advocates. Condit and collaborators frame their results as support for a more adequate theory of metaphor and its effects, adapting a framework due to Joseph Stern in which a large range of possible associations is filtered by context and by the audience to produce a particular interpretation of a metaphor. This implies that the use of metaphor to induce a desired understanding would require an understanding of the specific audience, and control over many aspects of the act of communication.

These studies drive home the lesson that, "the critical analysis of metaphors cannot successfully be conducted in an off-hand fashion that is inattentive to the workings of language and metaphor." (Condit and Condit 2001, p 36) Similar critiques could surely be made of other claims advanced by history and philosophy of biology authors, such as the claim that the application to the genome of the common-sense semantic notion of information ('meaning') promotes genetic determinism (Oyama 2000b, Griffiths 2006). This is an important reality check for the many authors in history and philosophy of biology who have advocated 'refiguring life' (Keller 1995). Like the deficit model, the history and philosophy of biology literature has neglected the fact that audiences actively process information to construct autonomous understandings of science, rather than merely mirroring more or less imperfectly the understandings offered to them.

When viewed as an attempt to forge tools with which to communicate scientific content, the history and philosophy of biology literature looks naïve. But before giving up on that literature we should realise that this is not the only aim of most authors in history and philosophy of biology. They are also, and perhaps primarily, trying to find metaphors that embody an adequate generalized under-

standing of the 'lessons' and expectations to be derived from current biology. Unlike specific research findings, such broad visions of science do not pre-exist their formulation in more or less figurative language. Reading the literature on the recipe metaphor from this alternative perspective reveals some shortcomings in the analysis by Condit and her collaborators. Those authors lay great stress on the gendering of the two competing metaphors (blueprint as male, recipe as female): "when the scale is held constant (industrial baking is compared to large buildings or a homebuilt cabin is compared to homemade bread), the similarities between the metaphors are most evident. Thus, blueprint and recipe metaphors differ primarily through their gendering…" (Condit et al. 2002, p 306). As for the thought that the recipe metaphor will help combat determinism, "Perhaps the social critics who recommend the recipe metaphor, most of whom have been female, see the recipe as more passive and amenable to individual control because, as females who have been conditioned to traditional mores, they may be more familiar with recipes than blueprints" (Condit et al. 2002, p 306).

But whilst the gendering of the recipe metaphor is likely of importance for its reception by some audiences, it is not a plausible view of the motives of its advocates. The recipe metaphor was first introduced as an alternative to the blueprint metaphor by the ethologist Patrick Bateson in a popular talk for the BBC in the early 1970s (Bateson, personal communication) and in a scientific paper on behavioral development written around the same time (Bateson 1976). It was taken up by Richard Dawkins and most later uses can be traced back to his extended discussion of the recipe metaphor in *The Blind Watchmaker* (Dawkins 1986, esp. 295–6). Thus, whilst Condit and her collaborators correctly note the 'homeliness' of the recipe metaphor as one of its distinctive rhetorical features, this is more likely to reflect a tradition of 'homely' metaphors in ethology (e.g. the 'flush-toilet model' of Lorenz 1950, p 256) than its gendered origin.

Condit and collaborators identify the errors that result from neglecting the role of the audience in interpreting the recipe metaphor, but they misunderstand the intentions of those who produced this metaphor. Those authors used the metaphor to formulate their own understanding of genomics as much as to communicate it to a wider audience. They were concerned with the difference between a description of the final product (blueprint) and a set of instructions for making a product (recipe). They believed that in certain key respects the genome-phenotype relationship is strongly disanalogous to the first and more closely analogous to the second. Condit and collaborators have criticised this claim by identifying examples in which the claimed disanalogy fails to hold. Thus, for example, Bateson and Dawkins both emphasised the fact that, whereas the elements of a blueprint each correspond to an element in the final product, the instructions in a recipe do not. Condit et al. find this point in later authors and reply with a counterexample: the individual elements in a salad recipe *do* correspond to elements in the salad (Condit et al. 2002, p 306). They also notice that builders deviate from blueprints in ways that reflect the resources and materials available to them, so that contextual factors affect outcomes just as they do with recipes. They suggest that, "the relative appeal of the recipe metaphor lies not in an escape from deterministic language but in its associations with the per-

sonal rather than industrial, the nurturing rather than controlling, and with creative individual action. Recipes come from the realm of the familiar, the personal, and the small, rather than the commercial and the large" (Condit and Condit 2001, p 32). But this is not the appeal the recipe metaphor had to its originators.

In his use of the recipe metaphor, Bateson was trying to convey a specific concern about appeals to information in the explanation of behaviour that can be traced back in his own research tradition to the late 1960s: "although the idea that behavior patterns are 'blueprinted' or 'encoded' in the genome is a perfectly appropriate and instructive way of talking about certain problems of genetics and evolution, it does not in any way deal with the kinds of questions about behavioral development to which it is so often applied" (Lehrman 1970, p 35). The relationship between genes and behaviour is mediated by chemical properties such as the stereochemical affinities of gene products, or their diffusion rates. Bateson chose the metaphor of a recipe because it involves the same kind of causal interactions as development — chemical ones. The metaphor of chemical engineering as opposed to mechanical engineering would have conveyed his meaning just as well, but the source domain of that metaphor would have been less familiar to his audience. Similar criticisms of the blueprint metaphor are readily found in the writings of developmental biologists generally, not only in those concerned with behavioral development in particular. Thus, in 'Metaphors and the role of the genes in development' H. Frederick Nijhout, best known for his work on morphogenesis in butterflies, writes that "[t]he simplest and also the only strictly correct view of the function of genes is that they supply cells, and ultimately organisms, with chemical materials" (Nijhout 1990, p 444). Nijhout does not use the word 'recipe' but it is on the tip of his tongue: protein-coding sequences in the genome are a list of ingredients. So the recipe metaphor was intended, not only as a device for popularization, but as a vision of developmental biology and one intended to be taken as seriously as William Harvey's analogy between the heart and a pump. Critics and defenders (e.g. Rosenberg 2006) of the blueprint metaphor were not simply disputing which metaphor will best communicate to the public their shared vision of biology. They were also disputing which vision is correct, and hence which should be communicated.

In this section, I have suggested that public understanding of genetics and history and philosophy of biology are pursuing significantly different projects when they evaluate genetic metaphors. Public understanding of genetics emphasizes the impact of metaphors on diverse audiences and does not usually see the chosen metaphor as partly constituting the science to be communicated (but see Bucchi 2004). In contrast, history and philosophy of biology is concerned with competing visions of science embodied in metaphor. It is concerned with the correct 'big picture' of biology to communicate to the public, and has paid too little attention to the active role of the public in constructing their own 'big picture', a process in which the material offered to them by science communicators will be only one of many influences. But although distinct, these projects have a great deal to offer to one another. Public understanding of genetics could usefully integrate the idea that what needs to be communicated is often

a 'vision' of biology which cannot readily be separated from the figurative language used to express it (Stotz and Griffiths 2008). Conversely, in so far as history and philosophy of biology wishes to make a contribution to improving public understanding, it will have to pay attention to research in public understanding of genetics.

What should the standard of success be for science communication?

We have seen that rejection of the deficit model led to an emphasis on the process by which audiences construct their own, autonomous understandings of biology using ideas from multiple sources. A substantial body of empirical research has documented that this is a more adequate model of what public understanding of science consists in than viewing it as the more or less successful transmission of a message. The constructivist model also suggests a standard by which public understanding is to be assessed: it is adequate to the extent that it allows people to function effectively in situations in which they have to deal with the biological sciences. These include personal choices, such as whether to take a genetic test or consume a GM product, and collective choices, such as whether to support the California referendum proposition to fund stem cell research. Using this standard, the 'best' understanding may in some cases be no understanding. The concept of 'rational ignorance' suggests that laypersons do not assimilate some biological information for the same reason biologists do not assimilate information they encounter about derivative contract pricing — they have more pressing matters to think about.

History and philosophy of biology has shown little interest in this aspect of science communication research. It has been concerned with how best to understand biology on the assumption that understanding it *is* important. This suggests that if the two fields are to enter into a productive dialogue they will need to distinguish two issues. The first is whether the constructivist standard is the correct way to evaluate the public understanding of biology. The second is whether current understandings are adequate when compared to this standard. Most public understanding of genetics research to date has focused on the first issue, documenting that the public "processes messages about genetic research complexly and critically" (Bates 2005, p 47). However, demonstrating that laypersons have *autonomous* understandings is not the same thing as demonstrating that those understandings are *functional* for the people that create them. No doubt a focus-group study in early 20th century Europe would have shown ordinary citizens processing scientific information about race and heredity in a complex way and in the light of existing ideas derived from folk tradition, popular culture and personal experience, to produce autonomous understandings. Nevertheless, the understandings they created were disastrous, certainly for their societies collectively, and often for themselves individually. Thus, whilst the critics of genetic determinism in history and philosophy of biology would benefit from taking on board the sophisticated model of public understanding that has been generated by the past twenty years of work in public understanding of genetics, this does not invalidate their continuing concerns about deficiencies in public understanding.

Conclusion

History and philosophy of biology and public understanding of genetics can and should learn from one another. History and philosophy of biology does not simply recapitulate the errors of the 'deficit model' because it does not believe that the aim of communicating biology is to bring public understanding of biology into line with that of biologists themselves. However, work in history and philosophy of biology *has* often assumed another aspect of the deficit model, namely that improving public understanding is a matter of 'transmitting' the right thing to the public, even if the right thing consists of contestable visions of contemporary biology (Stotz and Griffiths 2008). Since the amelioration of public understanding is an explicit aim of many authors in history and philosophy of biology, there is an urgent need for them to assimilate the sophisticated approaches that have been generated by a quarter-century of work in public understanding of science.

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Modelling complex systems and guided self-organisation

Mikhail Prokopenko

Centre for Complex Systems, Faculty of Engineering and IT
The University of Sydney, NSW 2006, Australia

Email: mikhail.prokopenko@sydney.edu.au

Abstract

We explore several opportunities created by a new approach to science, engineering and management: *complex systems*. By distinguishing between complex and complicated systems, we reflect on different design approaches, and discuss the advantages offered by guided self-organisation. Pointing out that several modern challenges are characterised by critical dynamics, cascading failures and non-trivial information flows, we attempt to highlight the importance of cross-disciplinary quantitative methods, as well as novel educational initiatives in Complex Systems.

Introduction

Complex systems is a new approach to science, engineering and management that studies how relationships between parts give rise to the collective behaviours of the entire system, and how the system interacts with its environment. Dynamics of a complex system cannot be predicted, or explained, as a linear aggregation of the individual dynamics of its components, and the interactions among the many constituent microscopic parts bring about macroscopic phenomena that cannot be understood by considering any single part alone ("the whole is more than the sum of the parts").

Complex systems are often confused with complicated systems which may also comprise a large number of components and interactions. This is not surprising: after all, both concepts express a notion opposite to being simple or straightforward. The two terms also share a common Latin origin: *complexus* originates from *complectī* ("to entwine or encircle"), derived in turn from com- ("together") and plectere ("to weave"), while *complicātus* is a form of *complicāre* ("to fold together") which augments com- ("together") with plecāre ("to fold"). So how significant is the difference between *weaving* and *folding* some parts together?

Naïvely, this subtle distinction reflects on different design approaches: one flexibly weaves and interconnects the elements, revealing elastic and resilient emergent forms; while the other rigidly folds the components and reduces their interaction potential, following a prescribed procedure towards a planned, if often brittle, structure with predictable behaviour.

This divergence becomes even more apparent when one compares natural organisms which have evolved their adaptive and self-organising responses, on the one hand, with artificial machines which conform to precise blueprints and operate under predefined protocols, on the other. As noted by a well-known biologist, Carl Woese: "Machines are stable and accurate because they are designed and built to be so. The stability of an organism lies in resilience, the homeostatic capacity to re-establish itself."

One striking example of biological complexity is a swarming behaviour exhibited by schools of fish, herds of wildebeest, and flocks of birds. In response to a predator, many schools of fish display complex collective patterns of spatial aggregation, so that small perturbations can quickly cascade through an entire swarm in a wave-like manner transferring the survival-critical information.

While complex self-organising systems adaptively process information in creating and exploiting emergent non-deterministic patterns, our engineering and management practice is driven by data, producing complicated designs and predictable deterministic regimes that prove brittle to unexpected malfunctions over and over again (cf. Table 1, Figures 1 and 2).

Table 1: Complex vs Complicated Systems.

Complex	**Complicated**
Evolved adaptive response	Designed for performance
Emergent non-deterministic patterns	Predictable deterministic regimes
Self-organisation: hard to predict	Blueprint: verification and testing
Resilient to perturbations	Brittle to malfunctions
Interdependent networks	Centralised management
Deals with information	Deals with data

As modern day infrastructure is growing more interconnected, the breakdown of a single transformer in a small substation can lead to massive cascading failures in a continent-wide electrical power grid, triggering further interruptions to traffic and communication systems; the emergence of a new pathogen in a remote village can give rise to a devastating global epidemic; the introduction of an exotic new species can eventually contribute to a chain of food-web disruptions and wide ecosystem collapses (cf. Table 2).

Figure 1: A complex system: a flock of auklets exhibiting swarm behaviour (source: Wikipedia).

Figure 2: A complicated system: a V6 internal combustion engine from a Mercedes car (source: Wikipedia).

Table 2: Examples of interdependent challenges.

Demographic & social	**Technological**	**Environmental**
overpopulation and ageing population	infrastructure degradation	climate change
epidemics and pandemics	cascading power failures	natural disasters
surge in irregular migration	transport and supply chain disruptions	animal and plant diseases

Living at the edge of chaos

Humans are typically inclined to use reductionist logic and analyse a system through a series of short, discrete scenarios, expecting a "correct response" to each scenario. However, not all scenarios have clear endings or known, correct answers. Modern power grids, communication and transport networks, mega-projects, and diverse social systems exhibit critical phenomena, characterised by phase transitions and tipping points, when a small change triggers a strong or even catastrophic response in the overall dynamics (Scheffer et al., 2009; Lenton, 2011) (cf. Table 3).

Table 3: Self-organising critical dynamics.

Physics	Avalanches
Technology	Power grids
Socio-technical systems	Traffic jams
Socio-ecological systems	Epidemics
Biological organisms	Collective behaviour (flocks, swarms, etc.)

There are several common features of complex dynamics as the involved agents (particles, fish, cars) are independent but interacting (cf. Table 4). However, as we move from physics to biology to social dynamics,

- precise nature of the interactions is less defined;
- there are more hidden variables;
- it is harder to influence the desired outcome, to "guide" the system;
- there are fewer theories of the systemic behaviour/risk.

Many hidden variables may change quickly, but collective behaviours (encapsulated in the corresponding order parameters) can adapt to critical situations. By varying control parameters (e.g., the system composition and the strength of interactions within it) one may trigger the system-level phase transitions. Haken introduced order parameters in explaining structures that spontaneously self-organize in nature (Haken, 1983; 2006). When energy or matter flows into a system typically describable by many variables, it may move away from equilibrium, approach a threshold, and undergo a phase transition. At this stage, the behaviour of the overall system can be described by only a few order parameters that characterize newly formed patterns. In other words, the system becomes low-dimensional as some dominant variables "enslave" others, making the whole system to act in synchrony.

Table 4: Common features of complexity.

Microscopic interactions lead to macroscopic effects
Sensitivity to initial conditions
Critical thresholds (tolerance margins)
Cascades of failures (-ve) or information flows (+ve)
Dynamics self-organise to a critical regime
Guided self-organisation: • triggered avalanche (controlled release) • islanding of power micro-grids • re-routing of traffic • vaccination, quarantine during epidemics

Guided Self-Organisation

Some of the hope for harnessing and guiding resultant self-organisation (Kauffman, 1993) is offered by the emerging discipline of Guided Self-Organisation (Prokopenko, 2009). This field is aimed at formalising the art of "herding cats", i.e., guiding collective behaviours towards desired outcomes, by optimising the ways to define agent interaction rules, set relevant constraints and select network topology.

One exciting application prospect is "social thermodynamics", inspired by classical thermodynamics and its extensions such as "physics of information" or "information thermodynamics" (Bennett, 2003; Lloyd, 2006; Prokopenko et al., 2011; Parrondo et al., 2015; Prokopenko and Einav, 2015;

Spinney et al., 2016). The main insight is that emergence of patterns within social dynamics may be understood and traced analogously to macroscopic thermodynamic regularities emerging out of microscopic statistical mechanics. The most significant theoretical task is to carefully interpret thermodynamic notions, such as entropy and energy, dissipative structures and irreversible processes, bifurcations and self-organisation, in the context of social interactions. While this general goal may not be achievable in the near-term, some specific areas where social dynamics are restricted by physical constraints may be formalised successfully, e.g., urban flows within an industrial ecology (Hernando and Plastino, 2012; Bristow and Kennedy, 2015).

A universal "language" is typically needed in order to comprehensively analyse dynamics generated by diverse complex systems and recognise distinct patterns of information and computation flow. Such lingua franca is provided by Information Theory operating on probability distributions that require only minimal structure (a probability measure) on the space of interest, and make no assumptions about a spatiotemporal structure of the system's space, its symmetries, differentiability, etc. (Polani, 2009; Prokopenko et al., 2009).

A recently developed framework of information dynamics systematically studies information processing in complex systems (Lizier et al., 2008; 2010; 2012) relating it to critical phenomena, e.g., phase transitions. This methodology suggests that discovering and quantifying information flows in complex systems could be a key to guiding the system dynamics towards desirable outcomes.

Changing the mindset

How can we predict the behaviour of systems that are too complex for our typical reductionist reasoning? The answers to this question are not intuitive or trivial, and in our opinion, would require a specific skill set which must be developed within educational programs explicitly dedicated to Complex Systems.

One of the biggest mysteries in the history of western cartography is a rather sinister image offered by Fool's Cap Map of the World, ca. 1580-1590 (cf. Figure 3). A possible interpretation of the map's message is that "the world is a sombre, irrational and dangerous place, and that life on it is nasty, brutish and short. The world is, quite literally, a foolish place." (Jacobs, 2014). And so, one may wonder if a "solution" to resolving numerous intricacies of our modern "post-truth" world, full of irrational and complex dependencies, should lie not within a novel mathematical framework, but rather in a new mindset.

Figure 3: Fool's Cap Map of the World (source: Wikimedia Commons).

Complexity, as a field of study, has shaped beyond the confines of physics, biology, mathematics, computer science and other disciplines which strongly contributed to its inception, and is on a verge of a rapid expansion within educational programs worldwide.

Professionals educated in science, engineering and management of Complex Systems will quantify the impact of unexpected events, design and analyse resilient socio-technological systems, and develop robust strategies for crisis forecasting and management. They will operate across discipline boundaries, in environments outside the experience of most professionals, providing key modelling and policy-informing inputs and insights to resolution of recurrent challenges across the globe.

The University of Sydney's postgraduate program in Complex Systems, including a Master of Complex Systems (MCXS) offered from 2017, is unique in the Southern Hemisphere. It leverages the research strengths of its newly created Centre for Complex Systems and is aimed at an exclusive cohort of high-achieving individuals.

MCXS provides strong comprehensive skills in computational analysis, modelling and simulation of collective and dynamic emergent phenomena, while engaging quantitative social and health sciences. The core units of study include large-scale networks, agent-based modelling, complex civil systems, self-organisation and criticality, statistics, stability analysis, and visualisation. The program also offers several internship opportunities, leading to specialisations in engineering, biosecurity, ecology, transport, and research methods, covering disaster management, computational epidemiology, nonlinear dynamics, smart grids, control theory, resilient supply chains and quantitative logistics.

It is expected that a number of MCXS graduates will continue on a pathway to a research career, advancing the field of Complex Systems in the 21st century, and harnessing the power of complexity in real-world applications.

More likely than not, the scope of Complex Systems research will keep expanding as we continue to explore our interconnected world: as pointed out by a physicist Heinz R. Pagels several decades ago, "Science has explored the microcosmos and the macrocosmos; we have a good sense of the lay of the land. The great unexplored frontier is complexity."

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Asian Diaspora Advantage in the changing Australian economy

Fazal Rizvi

The University of Melbourne, Australia[1]
Email address: frizvi@unimelb.edu.au

That the Australian economy is now inextricably tied to Asia is a fact that can no longer be contested. Our economic future clearly lies within the Asian region. Over the past four decades, a number of reports, dating back to the Fitzgerald Report (1978) and the Garnaut Report (1989), have shown how this is so. These reports have not only provided many examples of the growing links in trade and investment between Australia and Asia but have also pointed to their considerable potentialities. In 2012, the Henry White Paper, *Australia in the Asian Century*, described the growing footprint of Australian businesses, investors and entrepreneurs across the region, and explored how Australia might further take advantage of the opportunities associated with the so-called 'Asian century'. The current Government has similarly spoken of the importance of deepening our economic, political and cultural ties with Asia, and has established several initiatives to enhance these ties, including free trade treaties and the New Colombo Plan.

Every section of the Australian community has been encouraged to better understand and develop its links with Asia. What is now beginning to be also widely recognized is that Australia's growing Asian communities are uniquely placed to play a leading role in strengthening Asia-Australia relations. A deal of evidence now exists to show how Asian-Australian business communities are helping to expand Australia's relations of trade, investment and collaborations with Asia. Lacking, however, is an understanding of how this contribution might be better recognized, supported and expanded. This is the subject of a report that I recently co-wrote with Professor Kam Louie and Dr Julia Evans for the Australian Council of Learned Academies (ACOLA) for the Securing Australia's Future (SAF) Project, commissioned by the Australian Chief Scientists Office and the Commonwealth Science Council. In this talk, I want to discuss briefly some of our key findings.

The report, *Australia's Diaspora Advantage* (2016), was commissioned to investigate how Australia might take advantage of the language skills, cultural understanding and transnational networks that the Asian-Australian business communities clearly have. To fail to fully appreciate and utilize the multiple and diverse resources that these communities possess, it was assumed, was to risk throwing away a major advantage that Australia enjoys. We were asked therefore not only to provide an account that was helpful in understanding the nature and scope of the Asian-Australian business contribution but also suggest policy settings for boosting it. To do this work, our research was steered

[1] This short article is based on a report produced by Fazal Rizvi, Kam Louie and Julia Evans, *Australia's Diaspora Advantage*, (ACOLA 2016). (http://acola.org.au/wp/PDF/SAF11/SAF11%20full%20report.pdf)

and supported by an Expert Working Group (EWG) representing each of Australia's learned academies.

Diaspora Perspective

The Expert Working Group began its task by first attempting to locate relevant statistical data, but almost immediately faced the challenge of determining how to define the category of 'Asian-Australians'. It soon realized that, traditionally, much of the discussion relating to Australians of Asian backgrounds had been couched in terms of either ethnicity or migration; and that neither of these was entirely appropriate in exploring relations of international trade. The *ethnicity perspective*, for example, focuses on issues of identity and cultural traditions that Australians born in an Asian country continue to cherish. On the other hand, the *migration perspective* centres on the issues of settlement upon their arrival in Australia. It encourages analyses of the challenges that Asian-Australians face in attempts to 'integrate' into the Australian society. From a policy perspective, the migration perspective seeks to identify ways in which settlement might be better assisted by public policies and programs.

The main problem with both of these perspectives is that they assume a spatial logic that is based on a fundamental binary between an Asia that is 'there' and an Australia that is 'here'. In an era of globalization, in particular, such a binary does not work, for it fails to account for the continuing cultural, political and economic links that are now possible to be maintained across vast geographical distances. To overlook the importance of transnational experiences is to render an understanding of the contemporary Asian-Australian experiences that is at best limited. Furthermore, the migration perspective does not pay adequate attention to the lives of Asian-Australians of the second and subsequent generations, permanent residents, work visa holders, and those of mixed cultural backgrounds, who nonetheless view themselves as having an Asian background, and who believe that they therefore have a contribution to make in strengthening Asia-Australia relations. So, when statistical data are collected simply around the narrow categories of place of birth, migration and migrant settlement, it is necessarily incomplete, and is unable to provide a more thorough demographic account of the Australian society. In popular imagination, moreover, the idea of migration continues to be associated with deficit notions of marginalization and disadvantage. It pays little attention to the more economically productive aspects of Australia's cultural diversity.

Nor do the traditional sociological analyses centred on the notion of migration adequately capture the nature and growing significance of the transnational experiences and networks that many Asian-Australians are now able to access. It is clear that migrant experiences are not what they used to be, in a number of significant ways. For example, immigration no longer necessarily involves an expectation of permanent detachment from an immigrant's country of origin. Dual and even multiple citizenships have now become available to many Australians. Furthermore, an increasing proportion of immigrants to Australia from Asia are highly skilled, often at a very high level. Many come to Australia not only with intellectual but also financial resources, prepared to invest in both local and global enterprises. And, of course, the path from international education to migration has now become a well-trodden one. The decision of many Asians to migrate to Australia is also now

much better informed than ever before, as indeed is the ability of immigrants to remain connected with friends and family at home and elsewhere, using new communication and transport technologies. Many Chinese-Australians, for example, spend an average of two to three hours each day on WeChat or Weibo. This enables them to keep up with social trends and remain in touch with economic and political developments in China. Their familiarity with the shifting attitudes and customs at 'home' is thus much greater now than ever before.

These transformations demand a new way of looking at the Asian-Australian communities and their contribution to Australia. In our report, we refer to this new way of looking as the *diaspora perspective*. In our view, the term 'diaspora' better captures the transnational experiences of the people of Asian origins living and working in Australia, who are nonetheless able to remain in touch with their 'home' communities in a whole range of new ways, often in a manner that is organic and on an on-going basis, and in real time. For them, mobility across national boundaries does not mean abandoning cultural traditions and links. Their understanding of cultural and economic trends in their home country is no longer necessarily framed through ethnic nostalgia but through regular engagement. They are often active participants in the formation of these trends, even while they live in Australia. They are also able to access the global diaspora networks. In this way, their life experiences and aspirations are often located in transnational spaces.

The term 'diaspora' is of course quite old — at least 2,000 years — and was once used to refer to the Jewish communities living in exile, often under brutally harsh conditions. The modern use of diaspora, however, is much broader and more inclusive. It is widely applied to a whole range of communities, focusing not so much on displacement and assimilation, but on transnational connectivities and relationships that can now be maintained across vast differences, facilitated greatly by the new information and communication technologies and enhanced greatly by social media. Contemporary diasporas are characterised as groups of people belonging to a community who are dispersed across the globe, but remain connected to each other. They self-identify as being a member of the diaspora and choose to maintain ongoing links to a common place of shared family origin. Their leaving or arriving is never complete, but involves continuing processes of identity construction and reconstruction based on shifting historical, political and economic conditions.

If this is so, then the focus of sociological analysis must necessarily shift from issues of ethnicity and migration to transnational networks, the ability of people to have a sense of belonging to more than one place, and to regard their ethnic networks as having the potential to be politically and economically useful and productive. In this way, the diaspora perspective encourages an examination of the diversity, dynamism and mobility of Asian-Australian communities in ways that do not overlook their capacity to be 'embedded' simultaneously within Australia, their country of origin and across the globe. Our research attempted to understand the nature and scope of this 'embeddedness', in order to examine how the transnational networks that Australia's Asian business diasporas enjoy might have the potential to be a rich source of innovation, enterprise and

entrepreneurialism. It sought to provide an account of Australia's Asian business communities, the ways in which they utilized their transnational networks, enterprise and innovation, the opportunities they had, and the challenges they faced.

Diaspora Advantage

To develop a deeper understanding of Asian-Australian business communities, our research focused on Australia's Chinese and Indian communities as case studies. We recognized, of course, that China and India are complex and contested constructs. Neither is a homogenous nation. Both encompass vast cultural, linguistic and regional differences. Just the same, they denote entities that are meaningful to both the broader Australian community and to the Chinese- and Indian-Australians themselves. We chose China and India as case studies because they are now the largest Asian communities in Australia, with numbers that are growing rapidly. China is now Australia's largest trading partner and India's commercial significance to Australia is also growing. Our case studies involved analysis of the available data and commentaries, as well as interviews with over 100 Chinese- and Indian-Australians engaged in various business enterprises. We used these data not only to map the contribution of the Asian-Australian business communities to Australia but also to identify the challenges they confront.

The Diversity Council of Australia estimates that Australia's Asian communities now constitute over 17 % of its population, and are growing rapidly. Chinese and Indian are the largest Asian-Australian communities. The Chinese community in Australia is nearly 1.2 million people, while the Indian diaspora is over 650,000. Each of these communities is well represented in knowledge-intensive service-orientated industries. Each possesses strengths and expertise in the areas of professional service and in fields that are greatly assisting Australia's transition from an economy based on resources to a more diversified economy. In a whole range of ways, both communities are helping to stimulate economic growth in most areas of the Australian economy. Significantly, they are driving new developments in international education, tourism, professional and technical services, the creative industries, and the retail trade of cultural goods.

While most Chinese- and Indian-Australians work in enterprises that are local, all our interviewees indicated that they had given a great deal of thought to the potential of their transnational networks, and how these might be harnessed to develop enterprise and innovation. Many had already established initiatives to drive export activities. Almost all interviewees believed that the contribution of the Asian business diaspora communities to the Australian economy could be greatly boosted through greater use of their cultural knowledge and skills and their ethnic networks across the globe. They regarded their networks to be a kind of 'diaspora advantage'. For them, the idea of 'diaspora advantage' suggests that the linguistic skills, cultural knowledge, transnational networks and the diversity of perspectives that they bring to Australia constitute an advantage that not only benefits them personally but also has the potential to help Australia more broadly, to maximise its attempt to extend its innovation and economic links with Asia.

When it comes to doing business between Australia and Asia, the value of this advantage is immense. It has the potential both to assist Australia's attempts to become better integrated into the region's economy, and

to help its transition from its reliance on resources to knowledge-based industries. Many of Australia's Asian diasporas are already engaged in business and trading activities across Australia and Asia. Many are involved in key knowledge-based service industries as creators of knowledge, products and services and as consumers of them. They are playing an increasingly significant role as investors, creators, mediators and consumers. With mobile phones, the Internet and the likes of Skype and Facebook speeding up the flow of information and ideas, Asian business diasporas have been able to occupy the space here, there and everywhere more easily, and have been enabled to accelerate the establishment of trusted people-to-people links and obtain knowledge of the local culture, emerging markets and business opportunities. Through their transnational 'embeddedness', the business diasporas have capabilities to establish links both more quickly and efficiently. They are not constrained by having to organise relationships through hierarchical models of social and economic organisation allowing for the transformation of relationships, resources and business activities in a highly responsive way, where and when needed.

As the world's most populous region, Asia is expected to become the world's largest economic zone for both production and consumption. Indeed, Asia already has the largest middle class, with its consumption patterns increasingly shaping the world economy. While global problems such as rising income disparities, social instability and environmental risks will clearly also affect their political and economic institutions in most Asian countries, they appear relatively stable, enabling rising long-term income trends to continue. These trends are supported by the rising educational aspirations throughout Asia and the preparedness of many governments in Asia to invest heavily in education, training and research, and innovation and entrepreneurialism. With Asia becoming an engine of the world economy, the flow of ideas, capital and people will accelerate and result in new modes of investment, production, distribution and consumption. These transformations are likely to produce new trade opportunities for Australia, signalling a shift from an economic reliance on resources, such as minerals and energy, towards a global demand for culturally-modulated knowledge-based products and services, many involving sound and reliable cultural relationships.

With the emerging Asian middle class demanding new cultural goods and services, Australia will clearly have further opportunities, but will only be able to realise them if it relies upon all of its human resources, especially those people who have deeper understanding of the region and the dynamic changes that are transforming most parts of Asia. For Australian services to become more cost-efficient and productive, intercultural skills will become increasingly important because with such capabilities come greater business agility, adaptability and creativity. This underlines the importance of people who are locally embedded in Australia but globally stretched and adept at negotiating the transnational economic space. The diaspora advantage is linked to these factors, and has already proved helpful in driving trade and entrepreneurialism.

Innovation and Enterprise

A demographic analysis of the contemporary Chinese and Indian communities in Australia indicates that they are generally highly motivated, with a great proportion

possessing a university degree and engaged in high-skills industries that often require a predisposition towards innovation, entrepreneurialism and the commercialisation of knowledge. Their business activities include employment in the corporate sector, networked business activity (such as franchising and licensing models), representing overseas business interests, and business ownership and investment. Also evident over the last decade are marked increases in business ownership and investment visa applications in Australia by Chinese and Indian diasporas. In 2011, an estimated 45,500 business were owned and operated by Australia's China- and India-born populations. Between 2006 and 2011, businesses owned by Australia's China-born population rose 40 per cent and 72 per cent by those born in India (mostly small to medium enterprises, SMEs). Between 2012 and 2015, China was the largest source country for the *Business Innovation and Investment Visa* program, accounting for around 90 per cent of applications, nearly all being granted.

What these quantitative data reveal is that the Chinese and Indian business diasporas have now become highly active in the business space in Australia. The qualitative interviews, however, indicate a more nuanced picture, of how many of their businesses are in fact in areas that involve either a joint transnational operation or a service provided to other members of the diaspora within Australia. They are deeply conscious of their diaspora advantage. They believe that their language and cultural capabilities, along with their transnational connectivities, equip them to seize new opportunities in the transnational economic space. As a result, simultaneous involvement in multiple businesses is often common within the business. Examples of their entrepreneurial energy are best illustrated in their ability to establish start-ups, often emerging from opportunities provided through their networks. They also benefit from the mentoring provided by experienced entrepreneurs within their own community who have often overseen the development of their own business operations. Chinese and Indian business diasporas are also involved in investing in transnational companies, and in holding board directorships.

The interviews also indicate how diaspora networks are helpful in establishing new businesses in fields as diverse as science and technology, retail, tourism and international education. For example, in the field of cultural consumption, Australians of Chinese background, based in Adelaide, are developing Chinese tastes in and markets for Australian wine, while many Indian Australians have been enormously successful in positioning Australia as a major site of Bollywood films, whose audiences number in the hundreds of millions. In the areas of healthcare and social assistance, Indian- and Chinese-Australians are also active, creating new modes of production of goods, such as hybridized forms of medicine and services, including aged care. These examples show how transnational economic space is a site for much creativity and innovation, not least because it involves new conditions of cultural exchange and transformations.

Furthermore, through their networks, Australia's Asian diasporas make it possible for other Australian enterprises to become informed of the vibrancy and multifaceted growth that characterise a changing Asia. Australia stands to benefit from the diasporas' transnational stimuli and productivity in fields as varied as business, research commercialisation, education, and the cultural

and creative industries. While there are some major differences between the ways Australia's Chinese and Indian diasporas take advantage of the fast-emerging transnational economic space, there is a growing recognition among these communities of the opportunities inherent in this space. Both diasporas are continuing to explore its potential, with every indication that economic exchange through their networks will increase in the future. Much will depend on a prevailing economic climate that is supportive, and the extent to which rules and regulations govern business collaboration and exchange. Free trade policies will clearly help, but also necessary is a commitment to overcome the more informal cultural and political barriers faced by the business diasporas.

These barriers are multiple and arise at various levels, and in various ways. Within Australia, of key concern is the underrepresentation of Australia's Chinese and Indian business diasporas across government, institutions and industry in an era that not only demands the creation and diffusion of technical knowledge and research, but also cultural knowledge. Also important is the greater recognition and celebration of the leadership roles that Australians of Asian origin can play in driving more effective engagement with Asia. The Asian business diasporas also face issues in their own countries of origin, where their citizenship status is often ambiguous, and where they are frequently subjected to regulations that are unexpected and arbitrary, even if the government policies in China and India are broadly supportive of the commercial activities of their diasporas abroad.

Realising the Diaspora Advantage

Australia is, of course, not the only country that has recognized the importance of its diaspora advantage in the fast-changing transnational economic space. Other countries too have begun to address the challenge of recognising and utilising the resources of their own diasporas. The Chinese and Indian governments are deeply conscious of their global diasporas and have a desire to continue to utilise the knowledge and skills of their emigrants who have now settled elsewhere. In recent years they have begun to explore ways of using the resources that their diasporas abroad represent in forging and sustaining links for economic development and increased knowledge transfer and innovation collaboration. Chinese and Indian governments are therefore working on strategies to ensure that long-standing legal, political and administrative barriers to the participation of their diasporas abroad for the benefit of the Chinese and Indian economies respectively are overcome.

The policies of Canada, Germany and Singapore have also recognized the value of skilled diasporas. These nations have developed programs to attract highly skilled migrants and investors who have extensive business networks in Asia. However, much of the data that these national governments collect are inevitably based on the traditional categories of inbound and outbound migrants. As a result, these nations appear to be slow to develop a systematic evidence-based approach to engaging their Asian diasporas that contribute simultaneously to their own national interests but also assist the economies of the diasporas' countries of origin.

In looking at both China's and India's strategies, and policy programs of key advanced economies from around the world, it is clear that opportunities exist for Australia to lead the world in developing business diaspora initiatives, and to suggest a road map for maximising the economic potential for diasporas, namely, mobilising wealth via capital markets, facilitating diaspora investments, and transfering human capital. Elements of this road map align with aspects of the *National Innovation and Science Agenda* and similar initiatives, and we highlight the potential role of the Australian Asian business diasporas' involvement in them. But a piecemeal approach is not sufficient. What is required is a coordinated national approach to diaspora policy.

Such a policy might consider ways in which the increased representation of Australia's Asian business diasporas could support national business programs and research collaborations and assist with advancing Asian capabilities within agencies and organisations that provide advice on doing business in Asia. Ways in which we can groom Asian capabilities in Australian students and early career professionals, as well as pathways for attracting talent, might also be considered. Also requiring attention are ways in which trade delegations might be able to improve their relevance and return on investment. Such a response might consider the conditions for Australia's Asian diasporas and the social, economic and political conditions that can further realise the advantage they represent. This suggests a step forward from previous notions of migration towards diaspora as a more apt concept with which to make sense of the ways in which people of Asian origins live and work in Australia. What is needed is a vision for Australia in Asia, which recognises the complexities of Asia and seeks a deeper understanding of its regionality and diverse interests. In doing so, fertile conditions for fluid engagement between people, policy and place will better position Australia to anticipate, and swiftly respond to, opportunities in Asia in a highly nuanced, Asia-capable way.

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A note from the 1960s: science communication as a solution to complex science

Joan Leach

Director, Australian National Centre for the Public Awareness of Science
Australian National University
Email: joan.leach@anu.edu.au

What was the problem to which science communication was the solution? A brief return to the 1960s to look at a key argument articulating both the problem of the complexity of science and its posited solution in "simple communication" revisits and revises one of the fundamental assumptions behind 50 years of effort to develop a field of science communication.

One of the most fraught questions concerning science at the end of the twentieth century was that scientific information and analyses were being generated at such a pace that no one could possibly "keep up." This was seen by many scientific institutions as especially problematic for a range of publics who need up-to-date scientific information to make decisions, to confront controversial applications of science and technology, and to live on a bedrock of evidence (Broks, 2006). The apogee of this mode of argument is the 1985 Bodmer report for the Royal Society of London that also posited the solution to this excess of information — improved science communication. In fact, this solution was seen as a natural progression from arguments made after WWII that were developed in the 1960s. The reason, then, for returning to the 1960s is not that the decade marks the beginning of science communication. The beginnings of science communication, as we would now recognise it, go back to the Victorian era, where popularisers were doing public demonstrations and celebrating the remarkable spectacles of electricity and magnetism (Knight, 2006). However, what happens in the 1960s is that the general scientific community starts to develop a theory about science communication and begins institutional means for directing it. As I shall argue here, using the example of Derek de Solla Price's canonical *Big Science, Little Science* (1963), a core part of that idea posits that complexity is the problem with science and science communication is a potential solution to that complexity — for scientists as well as non-scientific audiences.

The beginning of Complex Systems Theory in the 1960s turns out to be a landmark moment for science communication as well. One of the first systems that Complex Systems Theory wanted to study was science itself. Derek e Solla Price, a scientist and historian, wrote a canonical analysis of the state of science in *Little Science, Big Science*. We also credit him with popularising the idea that there is emerging a new kind of science — Big Science. De Solla Price remarks, "Because the science we have now so vastly exceeds all that's gone before, we have entered a new age swept clean of the old traditions. It's so complex that many of us have begun to worry about the sheer mass of the monster we have created." After developing a picture of the enormity and complexity of science as an institution, de Solla Price

comes to a somewhat glum conclusion. The institution of science is running up against its own capacities.

Crisis of Complexity

The worry that de Solla Price presents is that science itself has become so complex that it's no longer going to function along the norms and ideals that it sets for itself. He speculates about the way in which systems work when they come up against a growth ceiling and suggests that science has hit its growth ceiling. His second basic law of the analysis of science, turning science on science: "All the apparently exponential laws of growth must ultimately be logistic and this implies a period of crisis on either side of the date of midpoint for about a generation. The outcome of the battle at the point of no return is complete reorganisation or violent fluctuation or death of the variable. I would suggest that at some point during the 1940s or 50s, we passed through the mid-period in general growth of science's body politic." And, thus, science must change its ways of working or enter crisis.

Of course, in the 1960s, there was another theorist of crises, probably one of the most famous of the 20th Century, Thomas Kuhn. In the *The Structure of Scientific Revolutions* (1962) Kuhn posited that science infrequently is in crisis but it is an unsettling experience for individual scientists even if it results in "scientific progress". So, what do you do in the face of this crisis?

One of the things that emerges is a contemporary notion of science whereby scientists communicate their way out of crises. First, scientists need to revisit their modes of communication with their professional peers. Then, there is a need to communicate across disciplines that are increasingly narrow. Finally, scientists must appeal to larger and more diverse audiences, usually labeled as "the public". So, from worries about crisis in science, an idea about communication and how scientists organise their communication with one another emerges.

Given that science communication is posited at a solution to the complexity of the scientific system, the idea that science communication itself is prone to difficulties is yet another problem in the scientific system. De Solla Price indicates that professional communication is becoming more complex: it too has to change. Two pieces of evidence are marshaled in support of this view, the first, a prescient observation of scientific publishing, and the second, a somewhat damning indictment of scientific reading habits. Writes de Solla Price, "scientific communication by way of the published paper is, and always has been, a means of settling priority conflicts. It's claim-staking rather than avoiding them by giving information. Scientists have a strong urge to write papers but a mild one to read them. Scientists must aim to establish and secure the prestige and priority they desire by means more efficient than the traditional device of journal publication." De Solla Price thought that improved professional communication could go a number of ways: there might be other outlets in which scientists could engage in claim-making, such as collective archives and pre-prints. Given long journal lead times and de Solla Price's observation in 1962 that "less than 10% of the available serials were sufficient to meet 80% of the demand [of readers]" (p. 75), de Solla Price is quite prescient about the emerging dire state of academic publishing in science, where more recent estimates suggest that only 50% of publications are ever read by anyone other than the author and editor (Evans 2008).

Proliferation of popularization

The 1960s responses to complexity are driven by a worry that complexity in science is going to have a negative impact on both scientists and knowledge. In addition, there is growing awareness that those outside of science are increasingly unaware of scientific work. In 1963, a collection of the Australian science comic, *Frontiers of Science*, was introduced by Stuart Butler and Robert Raymond repeating de Solla Price's observation, "such is the pace of the expansion of knowledge and the need for specialization that even scientists themselves confess a growing sense of helplessness. The necessity of concentrating ever more closely on their own field prevents them from keeping up with parallel developments in other fields, even those quite closely related to their own." But, then, they add, "If this is so for scientists, how much more baffling had the world become for the non-scientists, the readers of the newspapers, who wonder each day what new headlines will face them?" A collection of science comic strips, then, becomes an attempt to face the rapid pace of the expansion of knowledge — the complexity of the scientific system — with another form of communication, the comic. As Bauer (2009) notes, the number of popular science articles in the mainstream media seems to have peaked in the 1960s. But in addition to popular science "articles", the 1960s also seems to have proliferated forms of science popularization — the comic, "scientific advertising", science theatre, science fiction based on scientific research, and others. Much of this seems to have been generated by this founding anxiety that science had just gotten too complex and the need for new modes of communication was urgent.

But even if science had gotten too complex in the 1960s, it does not necessarily follow that popular communication was any simpler in form or even in function. Much like de Solla Price's earlier observation that the complexity of the scientific system was producing too much scientific communication, and quite possibly in the wrong format, it is worth considering this thesis in relation to popular science of the period. Scholars of science communication have largely focused on science journalism in print media as an indicator of the state of science communication in any one period (Broks 2006). By this indicator, the 1960s was a high point for popularization: there was a proliferation of popular science magazines, major news outlets like the *New York Times* began publishing more science (culminating in a stand-alone science section in 1978). But what of the move of scientists themselves to communicate more publicly — for example in the scientific comics introduced above? In 1961, Alvin Weinberg was worried enough to write about what he saw as the three dangers of big science — "journalitis, moneyitis and administratitis" (Capshew and Radder 1972). While he criticizes the proliferation of science journalism for muddying the waters between serious science and popular science, his biggest concern seems to be that of de Solla Price, "...the enormous proliferation of scientific writing, which largely remains unread in its original form and therefore must be predigested, one cannot escape the conclusion that the line between journalism and science has become blurred." Weinberg's worry is not only that an undiscerning public (or politician) misunderstands the lines between journalism and science, but, rather, given the complexity and enormity of

the scientific enterprise, scientists themselves need popular forms to "pre-digest" unread scientific papers.

This take on complexity in science is a bit different than other narratives of the rise of science communication (see for example, Logan 2001) and focuses on how some scientists, at least represented by de Solla Price and Weinberg, were starting to think of the scientific enterprise in the 1960s. At least one answer to growing complexity was better science communication. It seems that this led to a so-called "golden age" of science journalism as well as an experimental period where scientists themselves felt able to popularize science. The focus on print journalism in many studies of science communication eclipses the historical motivation for more and better science communication and assumes that scientists themselves were bystanders to a largely media-driven phenomenon. The suggestion here is that scientists recognized the increasing complexity of the scientific system, saw it as a problem, and saw better science communication as a way forward for professional science communication and popular science. The "problem", as defined by the 1960s was less of a problem of the "public" but one of the complexity of science.

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Thesis abstract

Naming and visualising people in the discourses of disability

Pei Soo Ang

Abstract of a thesis for a Doctorate of Linguistics submitted to Macquarie University, Sydney, Australia

Disability is a multi-faceted discursive construct shaped by diverse motivations and perspectives. To understand this complex construct, this thesis examines the aspects of naming and visualising people in a Malaysian newspaper. Although the focus is on disabled persons, the non-disabled are also examined as they co-construct the discourses.

This study draws on Fairclough's (2010) dialectical-relational critical discourse framework and Candlin and Crichton's (2011) multi-perspectival methodology. The data sets comprised 863 news texts on disability issues and 1002 photographs accompanying these texts. They were sourced from *The Star*, a mainstream Malaysian English newspaper (July 2008–June 2011). Corroborative perspectives from 46 interviews with various stakeholders were also used to provide insights into social institutional practices.

On naming practices, the nominal group structure and lexical choice in name phrases, as well as the voices that employed these phrases were analysed. Findings show the multiplicity of voices have different motivations for their choices of names. On visual representations, van Leeuwen's (2008) visual actor analytical framework was utilised, aided by Garland-Thomson's (2006) taxonomy of visual rhetoric of disability as well as the analysis of *affect* from Appraisal Theory (Martin and White, 2005). Findings suggest symbolic *exclusion* of disabled actors. Extending from these, this thesis also proposes the *perspectivisation* of disability. It describes the visual framing of disability on a cline of *perspectivising/personising* images and the emotive dimension on the *enabling/disabling* cline. Subsequently, the Visual Discourse of Disability Analytical Framework (VDDAF) is developed as a tool for analysing and understanding the effects of this *perspectivisation*.

By analysing the practices of naming and visualising disabled persons in news discourse, this study reveals discriminatory practices affecting the social standing of disabled persons. To be inclusive, the discourses should reflect dignified representations of the persons as members of society, and disability as part of human diversity.

Dr Pei Soo Ang
Department of Linguistics
Macquarie University
Sydney NSW 2109
AUSTRALIA

Email: pei-soo.ang@students.mq.edu.au
angps@um.edu.my

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Thesis abstract

Folate and vitamin D: The role of nutritional status and nutrigenetics in predicting levels of extracellular microRNA and circulation DNA methylation

Emma Beckett

Abstract of a thesis for a Doctorate of Philosophy submitted to the University of Newcastle, Australia

MicroRNA (miRNA) in systemic circulation are proposed as potential biomarkers for disease diagnosis and prognosis. However, miRNA profiles may also be modulated by other exposures such as nutritional status, and this may have consequences for use of miRNA as biomarkers, particularly in diseases for which diet is a modifiable determinant. Furthermore, little is known about the interactions that exist between these relationships and underlying variance in genes related to the processing of nutrients that may influence these relationships, or how these miRNA interact with other modifiers of gene expression, such as DNA methylation.

This thesis focuses on folate and vitamin D, two key micronutrients known to have the potential to influence gene expression. The data presented here investigate the relationships between these micronutrients and related nutrigenetics in predicting levels of extracellular miRNA and circulating DNA methylation status. The studies presented here were designed to capitalise on the availability of two well-characterised human cohorts: a case-control cohort of adenomatous polyp patients and healthy controls (n=263), and an elderly cross-sectional cohort (n=649). These are appropriate cohorts in which to investigate these relationships, as systemic circulating miRNA have been proposed as biomarkers for adenomatous polyps and colorectal cancer (CRC), diseases with known dietary modifiers of risk (including folate and vitamin D) which accumulate over a lifetime of exposures. Four candidate miRNA (let-7a, miR-15a, miR-21 and miR-155) were selected due to a combination of factors: each has known oncogenic or tumour-suppressor properties and each had existing evidence to suggest potential regulation by nutritional factors.

The first results chapter (Chapter 2) presents novel observations on the levels of systemic circulating levels of let-7a, miR-15a and miR-155 in adenomatous polyp cases relative to controls. Furthermore, by adding a sex specific level of analysis, it adds to the body of knowledge surrounding these miRNA and miR-21, which is currently proposed as a biomarker for adenomatous polyps. Novel data on the correlations between blood levels of folate and related micronutrients and the candidate miRNA are presented, with key findings including a positive correlation between red blood cell folate levels and all candidate miRNA, regardless of their tumour-suppressor or oncogenic properties. Stepwise regression analyses investigating the

correlations between systemic circulating miRNA levels and multiple dietary intakes, including vitamin D, are also presented.

Chapter 3 builds upon these results by incorporating common folate and vitamin D related genetic polymorphisms into the analyses. The relationships between these polymorphisms, systemic circulating miRNA levels, and risk for adenomatous polyps were assessed, as well as interactions with nutrient status. Statistically significant relationships were identified between multiple polymorphisms and risk for adenomatous polyps, and miRNA levels, as well as potential interactions between folate status and genotype in predicting miRNA levels. These are the first reported observations of the potential relationships and interactions between miRNA profiles and nutrigenetic variance.

As the human cohorts used can only demonstrate correlation and not causation, Chapter 4 contains data obtained from cell culture models. Three CRC cell lines were used to demonstrate that miRNA are differentially expressed intracellularly and extracellularly under folate excess or deficient conditions, and following stimulation with the active vitamin D metabolite. Treatment with a DNA demethylating agent was also used to demonstrate that some of these processes are dependent on DNA methylation.

The relationships between vitamin D and DNA methylation were further investigated in Chapter 5. A sub-cohort was used to conduct a pilot study investigating the relationships between vitamin D status, methyl donor-related micronutrients and DNA methylation in genes of vitamin D metabolism. The relationship between methylation status in this pathway and the systemic circulating levels of the candidate miRNA were also assessed, and provides new information demonstrating the potential complexity of the complementary pathways for the regulation of cellular processes and pathways.

Together, the data in this thesis constitute a significant contribution to the body of knowledge surrounding the extracellular levels of miRNA, and how this may relate to vitamin D and folate status, related polymorphisms, DNA methylation, and intracellular miRNA expression levels. Relationships were identified between folate status, nutrient intake and systemic circulating levels of multiple candidate miRNA. Relationships identified between polymorphisms in related genes and systemic circulating miRNA levels support these observations, and these observations may link dietary factors to modified risk for disease.

This thesis expands our understanding of how nutrition and nutrigenetics can interact to modify nutrigenomics and disease risk. The data presented here for the candidate miRNA and two key nutrients, provide an impetus to investigate these relationships for other nutrients and miRNA, particularly those known to modify disease risk. These results have implications for the use of systemic circulating miRNA as biomarkers, and may also have implications for the future of personalised nutrition and personalised medicine.

Dr Emma Beckett
School of Environmental and Life Sciences
University of Newcastle
Newcastle NSW 2300
AUSTRALIA

Email: emma.beckett@newcastle.edu.au

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Thesis abstract

Essays on panel data econometrics and the distribution of income

Timothy Neal

Abstract of a thesis for a Doctorate of Philosophy submitted to University of New South Wales, Sydney, Australia

A great deal of research has been devoted to the distribution of income over the last century, and it is therefore reasonable to ask what could another dissertation possibly add to the subject? This dissertation will argue that the evolution of inequality over the last three decades, coupled with recent advances in panel econometrics and the collection of data, has made research into the distribution of income as highly pertinent today as any point in the past. The extraordinary shift in the distribution of income to the very top income earners, a phenomenon that has been occurring in a number of advanced economies over the last three decades, has only very recently become an issue of public concern and discussion. This is mostly due to a coordinated effort by a number of researchers around the world to unearth a new wealth of income share data from tax return information. A breakthrough in the availability of data allows this dissertation to examine research questions that were not feasible in the past. While the availability of data has significantly improved in recent times, so has the sophistication of large panel data econometrics (or 'panel time series' econometrics). This branch of econometrics has a lot to offer to research into inequality, and this thesis seeks to at least partly exploit the potential of using novel econometric approaches on newly available data in its pursuit to better understand the causes and effects of inequality on society.

The first chapter of this dissertation seeks to understand why the top 1% income share has risen so drastically in Anglo-Saxon countries (i.e. the United States, the United Kingdom, Australia, New Zealand, and Canada) but not in European countries. It adopts a panel cointegration framework to examine the determinants of top income shares using a wide variety of data sources. The analysis finds that economic openness, the size and ideology of government, the development of financial markets, top marginal tax rates, technological progress, and the strength of unions are all important determinants of top income shares. It demonstrates that the rise in inequality can't be explained by one or two 'chief drivers', but rather a multitude of factors that have been deliberately shaped by government policy in the affected countries, as well as through unavoidable structural changes to the economy. It also shows that the deregulation of labour, trade, and financial markets over the past thirty years has had significant side-effects on the level of equity in the economy.

The second chapter of this dissertation shifts focus to the effects (rather than the source) of rising inequality. For instance, in recent years a crisis of confidence in democratic political institutions has emerged in a

number of advanced economies, particularly following the Global Financial Crisis (GFC). The second chapter investigates the relationship between rising inequality and declining levels of political confidence in developed countries. A theoretical model is developed which argues that the income share of top earners affects confidence through its impact on the pre- vailing economic institutions. This prediction is tested empirically using multi-level modelling techniques from data provided by the World Values Survey and World Top Incomes Database. The result is a statistically significant negative correlation that is consistent with the chief proposition of the theoretical model. It suggests that one of the consequences of rising top income shares in Anglo-Saxon countries is less trust and confidence in democracy and its institutions. This finding is particularly relevant following the GFC, when alienation and disengagement from the political system worsened in a number of countries.

The third chapter of this dissertation continues this focus by examining the proposition raised by recent research that high inequality is partly responsible for the recent slow recovery in the United States. Rising inequality is thought to worsen recovery times directly through a phenomenon termed 'demand drag', and indirectly through its contribution to credit booms. By applying survival analysis techniques on business cycle data from U.S. states over the last seventy five years, the third chapter finds that inequality, fiscal policy, financial market conditions, and consumer credit are all strongly related to recovery speed. The results suggest that high inequality is responsible for approximately half of the recent recovery's lethargy.

Dr Timothy Neal
School of Economics
University of New South Wales
Sydney NSW 2052
Australia

Email: tjneal@gmail.com

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Thesis abstract

An examination of the process of motivational interviewing in the anxiety disorders

Mia Romano

Abstract of a thesis for a Doctorate of Philosophy submitted to Macquarie University, Sydney

Motivational interviewing (MI) is a collaborative, client-centred therapy style that aims to prepare people for behaviour change by helping them to explore and resolve ambivalence (Miller & Rollnick, 2002, 2013). MI was originally developed to treat problematic substance use but is increasingly used as both a stand-alone and adjunctive treatment for a variety of physical and mental health concerns. Proposed mechanisms of MI's success have been well specified. However, most research that examines MI mechanisms and particularly MI's proposed causal model has been conducted in the realm of substance use. Little is known about the generalisability of MI mechanisms from the substance use literature to the other problem areas where MI is being applied. The current thesis aims to address this gap by investigating the process of MI in areas beyond substance use. The thesis combines different approaches to address this central question.

The first two papers in my thesis investigate the current state of MI mechanism research. Paper One is a systematic review of evidence for the causal chain model proposed by Miller and Rose (2009). The review draws together research that tests paths of the causal chain in varying treatment domains. Paper Two is a meta-analysis that investigates MI mechanisms of change in populations diagnosed with mood, anxiety, psychotic, and eating disorders, and patients with comorbid mental health conditions. Taken together, the review papers pointed to limited use of control conditions and few investigations of MI mechanisms in the context of anxiety disorders. Therefore, the final three papers of this program of research aim to overcome these limitations and are dedicated to an empirical examination of MI processes in the context of social anxiety disorder (SAD). Each paper employs a sample of adults diagnosed with SAD who were randomised to receive either an MI-style treatment called Treatment Expectations and Engagement (TEE) or a supportive counselling control condition (SC) before all received group Cognitive Behavioural Therapy (CBT) for SAD.

Specifically, Paper Three investigates the capacity of MI to decrease ambivalence for people with social anxiety and examined the impact of client ambivalence on treatment outcome. Paper Four employs observational coding methods to examine the transition between therapist and client behaviour during MI sessions for social anxiety. Finally, Paper Five further explores the relationship between therapist behaviours and client language in MI, as well as the relationship between therapist and client variables and outcome.

The current thesis represents the first examination of MI process variables in an MI-style treatment for SAD. Given that MI is beginning to demonstrate positive effects in terms of engagement and treatment outcome in the realm of anxiety disorders, there is a need to investigate the process through which MI generates such effects. In doing so, we may be able to identify best practice for MI in the treatment of anxiety disorders. The research findings from the current thesis, taken together, support the proposal that MI mechanisms and treatment ingredients may be important to examine in the context of treatment for anxiety disorders, as well as partly being implicated in the treatment outcome of socially anxious individuals, specifically.

Mia Romano
Department of Psychology
Macquarie University
Sydney NSW 2109
Australia

Email: mia.romano@mq.edu.au

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Awards 2017

The following awards are offered by the Royal Society in 2017. Please see the specific page for details of each award.

Award	Eligibility		Closing date
Clarke Medal	Field: Seniority: Work considered: Location of work: Application by:	Botany Any "Significant contribution" Australia Nomination[1]	30th September, 2017
Edgeworth David Medal	Field: Seniority: Work considered: Location of work: Application by:	Any < 35 "Distinguished contribution" Australia Nomination	30th September, 2017
James Cook Medal	Field: Seniority: Work considered: Location of work: Application by:	"Science & human welfare" Any "Outstanding contribution" Southern Hemisphere Nomination	30th September, 2017
Warren Prize	Field: Seniority: Work considered: Location of work: Application by:	Engineering or technology In professional practice "of national or international significance" NSW Paper submitted to Journal	30th September, 2017
History and Philosophy of Science Medal	Field: Seniority: Work considered: Location of work: Application by:	History and philosophy of science Any "significant contribution to the understanding of the history and philosophy of science" Any Nomination or direct submission	30th September, 2017
RSNSW Scholarships Jak Kelly Award	Field: Seniority: Work considered: Location of work: Application by:	Any Enrolled research student on 1 July Research project NSW or ACT Application by student/ endorsed by supervisor	30th September, 2017

[1] Nomination by a senior member of the nominee's organisation (for example Dean, Pro Vice Chancellor of a university, Section or Division Head of CSIRO), or a member of the Royal Society of New South Wales.

Each year, the Royal Society of New South Wales makes a number of awards, mainly in the sciences, but also in the history and philosophy of science. They are among the oldest and most prestigious awards in Australia.

These awards are now open for nomination. *Nominations close on 30 September 2017.* They should be sent to the Presiding Member of the Awards Committee at ejameskehoe@gmail.com, with a cc to royalsoc@royalsoc.org.au.

The awards and the criteria for nomination are described below. All nominations must include:

• A letter of nomination setting out the case for the award;
• The nominee's full curriculum vitæ;
• Other supporting material as specified for the description of the award.

A nominator does not need to be a member or fellow of the Society. For some awards, researchers may nominate themselves. Awards allowing self-nomination will be noted below. The awards will be presented at the Society's next Annual Dinner, tentatively scheduled for Wednesday, 2 May 2018.

Clarke Medal 2017

The Clarke Medal was established to acknowledge the contribution by Rev William Branwhite Clarke MA FRS FGS, Vice-President of the Royal Society of New South Wales from 1866 to 1878. The Medal is awarded annually for distinguished work in the natural sciences of geology, botany and zoology done in Australia and its Territories.

The Medal is awarded by rotation in the fields of geology, botany and zoology. This year's award is in the field of Zoology in all its aspects, and nominations are called for the names of suitable persons who have contributed significantly to this science.

The Council requests that every nomination should be accompanied by a list of publications, a full *curriculum vitae*, and also by a statement clearly indicating which part of the nominee's work was done in Australia and which part was done overseas. Agreement of the nominee must be obtained by the nominator before submission and included with the nomination.

The winner will be expected to write a review paper of their work for submission to the Society's Journal and Proceedings. In cases where the Council of the Society is unable to distinguish between two persons of equal merit, preference will be given to a Member of the Society.

Nominations and supporting material should be submitted by email (ejameskehoe@gmail.com) to the Royal Society of New South Wales marked to the attention of the Honorary Secretary, not later than 30th September 2017.

The winner will be announced and the Medal presented at the Annual Dinner of the Royal Society usually held in April in the year following the award. The winner will be notified in December.

Edgeworth David Medal 2017

The Edgeworth David Medal, established in memory of Professor Sir Tannatt William Edgeworth David FRS, a past President of the Society, is awarded for distinguished contributions by a young scientist.

The conditions of the award of the Medal are:

- The recipient must be under the age of 35 years at 1 January 2017.
- The Medal will be for work done mainly in Australia or its Territories or contributing to the advancement of Australian science.

Nominations are called for the names of suitable persons who have contributed significantly to science, including scientific aspects of agriculture, engineering, dentistry, medicine and veterinary science.

The Council requests that every nomination should be accompanied by a list of publications, a full *curriculum vitae*, and also by a statement clearly indicating which part of the nominee's work was done in Australia and which part was done overseas. Agreement of the nominee must be obtained by the nominator before submission and included with the nomination.

The winner will be expected to write a review paper of their work for submission to the Society's Journal and Proceedings. In cases where the Council of the Society is unable to distinguish between two persons of equal merit, preference will be given to a Member of the Society.

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The winner will be announced and the Medal presented at the Annual Dinner of the Royal Society usually held in April in the year following the award. The winner will be notified in December.

James Cook Medal 2017

The James Cook Medal is awarded at intervals for outstanding contributions to science and human welfare in and for the Southern Hemisphere.

The James Cook Medal was established in 1947 with funding by Henry Ferdinand Halloran. Halloran, who had joined the Society in 1892 as a 23 year-old, was a surveyor, engineer and town planner. He did not publish anything in the Society's Journal, but he was a very enthusiastic supporter of research. Halloran funded what were to become the Society's two most prestigious awards, the James Cook Medal and the Edgeworth David Medal, the latter medal being for young scientists.

The Council requests that every nomination should be accompanied by a list of publications, a full *curriculum vitae*, and also by a statement clearly indicating which part of the nominee's work was done in Australia and which part was done overseas. Agreement of the nominee must be obtained by the nominator before submission and included with the nomination.

The winner will be expected to write a review paper of their work for submission to the Society's Journal and Proceedings. In cases where the Council of the Society is unable to distinguish between two persons of equal merit, preference will be given to a Member of the Society.

Nominations and supporting material should be submitted by email (ejameskehoe@gmail.com) to the Royal Society of New South Wales marked to the attention of the Honorary Secretary, not later than 30th September 2017.

The winner will be announced and the Medal presented at the Annual Dinner of the Royal Society usually held in April in the year following the award. The winner will be notified in December.

Warren Prize 2017

William Henry Warren established the first faculty of engineering in New South Wales and was appointed as its Professor at the University of Sydney in 1884. Professor Warren was President of the Royal Society of New South Wales on two occasions. He had a long career of more than 40 years and during this time was considered to be the most eminent engineer in Australia. When the Institution of Engineers, Australia was established in 1919, Professor Warren was elected as its first President. He established an internationally respected reputation for the Faculty of Engineering at the University of Sydney and published extensively, with many of his papers being published in the Journal and Proceedings of the Royal Society of New South Wales.

The Warren Prize has been established by the Royal Society of NSW to acknowledge Professor Warren's contribution both to the Society and to the technological disciplines in Australia and internationally. The aim of the award is to recognise research of national or international significance by engineers and technologists in their professional practice. The research must have originated or have been carried out principally in New South Wales. The prize is $500.

Entries are by submission of an original paper which reviews the research field, highlighting the contributions of the candidate, and identifying its national or international significance. Preference will be given to entries that demonstrate relevance across the spectrum of knowledge – science, art, literature and philosophy – that the Society promotes.

The winning paper and a selection of other entries submitted will be peer-reviewed and are expected to be published in the Journal and Proceedings of the Royal Society of New South Wales. Depending on the number of acceptable entries, there may be a special edition of the Journal and Proceedings that would be intended to showcase research by early- and mid-career Australian researchers.

The paper should be submitted by email (ejameskehoe@gmail.com) to the Royal Society of New South Wales marked to the attention of the Honorary Secretary, not later than 30th September 2017. The manuscript will be passed on to the Editor of the Journal for peer review.

The winner will be announced and the Medal presented at the Annual Dinner of the Royal Society usually held in April in the year following the award. The winner will be notified in December.

History and Philosophy of Science Medal 2017

The Royal Society of NSW History and Philosophy of Science Prize was established in 2014 to recognise outstanding achievement in the History and Philosophy of Science, and the inaugural award was made to Ann Moyal in 2015. It is anticipated that this Prize, like the Society's other awards, will become one of the most prestigious awards offered in Australia in this field. The winner will be awarded a medal.

Persons nominated will have made a significant contribution to the understanding of the history and philosophy of science, with preference being given to the study of ideas, institutions and individuals of significance to the practice of the natural sciences in Australia.

Entries may be made by nomination or direct submission. All entries should be accompanied by a full *curriculum vitae* and include a one-page statement setting out the case for award. In the case of nominations, the agreement of the nominee must be obtained by the nominator before submission and included with the entry.

The winner will be expected to submit an unpublished essay, drawing on recent work, which will be considered for publication in the Society's Journal and Proceedings during the following year.

Nominations and supporting material should be submitted by email (ejameskehoe@gmail.com) to the Royal Society of New South Wales marked to the attention of the Honorary Secretary, not later than 30th September 2017.

The winner will be announced and the Medal presented at the Annual Dinner of the Royal Society usually held in April in the year following the award. The winner will be notified in December.

Royal Society of NSW Scholarships 2017

The Royal Society of New South Wales is the oldest learned society in Australia, tracing its origins to 1821. It has a long tradition of encouraging and supporting scientific research and leading intellectual life in the State. The Council of the Society funds the Royal Society of New South Wales Scholarships in order to acknowledge outstanding achievements by early-career individuals working towards a research degree in a science-related field.

Applications for Royal Society of New South Wales Scholarships are sought from candidates working in a science-related field within New South Wales or the Australian Capital Territory. There is no restriction with respect to field of study and up to three Scholarships will be awarded each year. Applicants must be Australian citizens or Permanent Residents of Australia. Applicants must be enrolled as research students at a university in NSW or the ACT on 1st July in the year of the award.

Applications for a RSNSW Scholarship must include:

- 500-word summary of the work.
- Statement of the significance of the work, particularly within the broader context of your chosen field.
- *Curriculum vitae*, including details of their research candidacy.
- Letter of support from your research supervisor.

Applications should be submitted by email (ejameskehoe@gmail.com) to the Royal Society of New South Wales marked to the attention of the Honorary Secretary, not later than 30th September 2017.

Jak Kelly Award 2017

The Jak Kelly Award is awarded jointly with the Australian Institute of Physics to the best PhD student talk presented at a joint meeting with the AIP.

The award consists of an engraved plaque, a $500 prize and a year of membership of the Society. The successful applicants will present their work to a meeting of the Royal Society in 2018, and will be asked to prepare a paper for the Society's Journal and Proceedings.

The winners of both awards will be notified in December.

Archibald Liversidge:
Imperial Science under the Southern Cross

Roy MacLeod

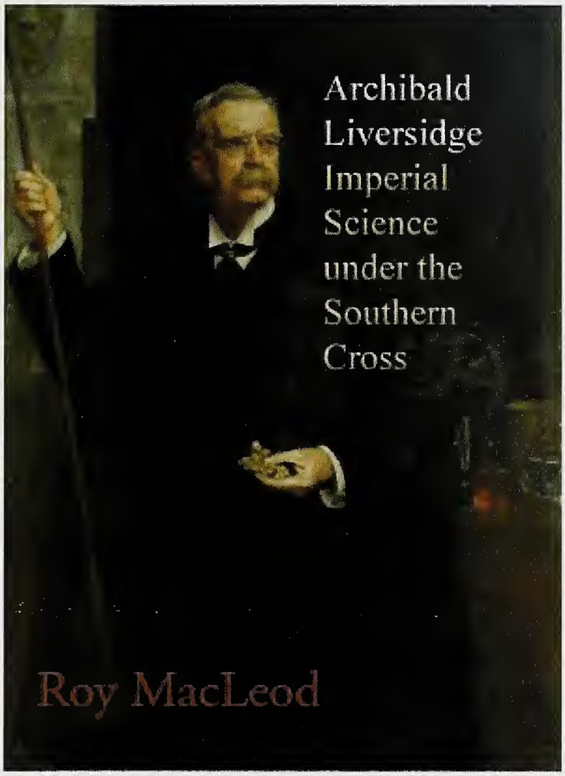
Royal Society of New South Wales, in association with Sydney University Press

ISBN 9781-9208-9880-9

When Archibald Liversidge first arrived at the University of Sydney in 1872 as Reader in Geology and Assistant in the Laboratory, he had about ten students and two rooms in the main building. In 1874, he became Professor of Geology and Mineralogy and by 1879 he had persuaded the University Senate to open a Faculty of Science. He became its first Dean in 1882.

In 1880, he visited Europe as a trustee of the Australian Museum and his report helped to establish the Industrial, Technological and Sanitary Museum which formed the basis of the present Powerhouse Museum's collection. Liversidge also played a major role in establishing the *Australasian Association for the Advancement of Science* which held its first congress in 1888.

This book is essential reading for those interested in the development of science in colonial Australia, particularly the fields of crystallography, mineral chemistry, chemical geology and strategic minerals policy.



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The Royal Society of New South Wales

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info@royalsoc.org.au (general)
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